Precipitation Processing System (PPS)

Algorithm Theoretical Basis Document (ATBD)

NASA Global Precipitation Measurement (GPM) Level 1C Algorithms

Version 1.8

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TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

REVISION HISTORY

Mod. #	Mod. Date	Description	Section Affected
1 (V1.3)	5/2014	Added two generic quality flags (-7 and -10).	Section 4
2 (V1.3)	5/2014	Added new section L1C-R GMI.	Appendix B
3 (V1.4)	3/2015	Added along-scan correction for GMI in Section A.3.1 and RFI warning check in Section A.4.1.	Appendix A
4 (V1.4)	3/2015	Added information for SSMI/S F19 in Sections D.3.1.2, D.3.1.3, D.3.1.6, and Table D-1.	Appendix D
5 (V1.4)	3/2015	Updated the intercalibration table for AMSR2 to 1C.GCOMW1.AMSR2.XCAL2014a-V.tbl in Section E.3 and Table E-1.	Appendix E
6 (V1.5)	2/2016	Added Tb to GMIBASE in Section A.1.1; removed Ta to Tb conversion from Section A.3.	Appendix A
7 (V1.5)	2/2016	Added Tb to TMIBASE in Section C.1.1, removed Ta to Tb conversion from Section C.3, and implemented the satellite intercalibration table XCAL2015-V in Section C.3.	Appendix C
8 (V1.5)	2/2016	Moved SSMI/S corrections performed by CSU from Section D.3 to section D.2, updated the intercalibration table version to XCAL2015-V in Section D.3 and Table D-1, and added SSMI/S sensor quality flag -126 in Section D.4.2.	Appendix D
9 (V1.5)	2/2016	Added incidence angles for each low-frequency channel to the AMSR2BASE file in Section E.2; updated the intercalibration table version to XCAL2015-V in Section E.3 and Table E-1.	Appendix E
10 (V1.5)	2/2016	Corrected ATMS channel frequencies and number of swaths in Section F.1.2; updated the intercalibration table version to XCAL2015-V in Section F.3 and Table F-1.	Appendix F
11 (V1.5)	2/2016	Updated the SAPHIR intercalibration table version to XCAL2015-V in Section G.3 and Table G-1; added checks for geolocation quality in Section G.4.1.	Appendix G
12 (V1.5)	2/2016	Corrected MHS channel frequencies in Section H.1.2, moved Ta to Tb conversion from Section H.3 to Section H.2, and updated the intercalibration table version to XCAL2015-V in Section H.3 and Table H-1.	Appendix H

Mod. #	Mod. Date	Description	Section Affected
13 (V1.5)	2/2016	Added new Appendix I.	Appendix I
14 (V1.6)	4/2016	Added -127 Error in Section D.4.2.	Appendix D
15 (V1.7)	5/2017	Updated the BASE algorithm ID from sensorBASE to 1BASEsensor (e.g., from GMIBASE to 1BASEGMI) throughout the ATBD.	Entire Document
16 (V1.7)	5/2017	Added a reference in Section 7.	Section 7
17 (V1.7)	5/2017	Updated the intercalibration tables version to XCAL2016-C in Table A-1.	Appendix A
18 (V1.7)	5/2017	Updated the intercalibration tables version to XCAL2016-V in Appendices C, D, E, F, G, and H.	Appendices C, D, E, F, G, H
19 (V1.7)	5/2017	Updated the SSMI/S flag definition for -126, -127, and 117 in Appendix D.4.2.	Appendix D
20 (V1.7)	5/2017	Added new Appendix J.	Appendix J
21 (V1.8)	10/2017	Updated Appendix C; added new warning flags in Appendix D, Section D.4.2; added new AMSR2 static files in Table E-1; added new Appendices I, J, K, and N; changed old Appendices I and J to letters L and M, respectively.	Appendices C, D, E, I, J, K, L, M, N

Notes: Version 1.4 changes apply to L1C product versions V03C (GMI, AMSR2), V02B (TMI, MHS, ATMS), V02C (SSMI/S F16, F17, F18) and V03A (SSMI/S F19). Version 1.5 and 1.6 changes apply to L1C product version V04 (GMI, TMI, SSMI/S, AMSR2, ATMS, SAPHIR, and MHS). Version 1.7 changes apply to L1C product version V05 (GMI, SSMI/S, AMSR2, ATMS, SAPHIR, and MHS). Version 1.8 changes apply to L1C product version V05 (TMI, SSMI/S, SSMI, AMSR-E, and AMSU-B).

1. INTRODUCTION

The Level 1C (L1C) algorithms are a collection of algorithms that produce common calibrated brightness temperature products for the Global Precipitation Measurement (GPM) Core and Constellation satellites.

1.1 OBJECTIVE

This document describes the GPM Level 1C algorithms. It consists of physical and mathematical bases for orbitization, satellite intercalibration, and quality control (QC), as well as the software architecture and implementation for the Level 1C algorithms.

1.2 L1C ALGORITHMS OVERVIEW

The Level 1C algorithms transform equivalent Level 1B radiance data into Level 1C products. The input source data are geolocated and radiometric calibrated antenna temperature (Ta) or brightness temperature (Tb). The output Level 1C products are common intercalibrated brightness temperature (Tc) products using the GPM Microwave Imager (GMI) as the reference standard.

The Level 1C algorithms contain the following major components:

- Orbitization.
- Satellite intercalibration.
- Quality control.
- Ancillary data calculations.

The detail of L1C algorithms and implementation depends on the details of each sensor. In this document, the Level 1C algorithms are described in a general sense. Individual sensor-specific details are provided separately in Appendices A through K: A) GMI, B) LIC-R GMI, C) Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI), D) Special Sensor Microwave Imager/Sounder (SSMI/S), E) Advanced Microwave Scanning Radiometer 2 (AMSR2), F) Advanced Technology Microwave Sounder (ATMS), G) Sondeur Atmospherique du Profil d'Humidite Intertropicale par Radiometrie (SAPHIR), H) Microwave Humidity Sounder (MHS), I) Special Sensor Microwave Imager (SSMI), J) Advanced Microwave Scanning Radiometer – Earth Observing System (AMSR-E), and K) Advanced Microwave Sounding Unit – B (AMSU-B).

1.3 L1C INPUT DATA DESCRIPTION

The input data to the Level 1C process are equivalent Level 1B radiance data. The input source to the L1C process is different for each sensor. Input data are geolocated, and radiometric calibrated antenna temperature (Ta) or brightness temperature (Tb) depending on the data availability from each sensor. An input data file could be an orbit with an arbitrary starting point or any arbitrary length. The input data format could be in binary, Network Common Data Form (NetCDF), or Hierarchical Data Format (HDF), etc. Detailed information on the L1C input data description for each sensor is included in the Appendices.

1.4 L1C PRODUCTS DESCRIPTION

The standard Level 1C products are the intercalibrated microwave brightness temperatures. All L1C products have a common format and are in HDF5. The format is designed to be simple and generic. One or more swaths are included in a product; a swath is defined as scan time, latitude, longitude, and data that match the latitude and longitude (lat/lon). Each swath includes scan time, latitude, longitude, scan status, quality, incidence angle, Sun glint angle, and the intercalibrated brightness temperature (Tc). The granule size is one orbit, which begins and ends at the southernmost point. There is no overlap scan in the standard L1C products.

A more detailed L1C product description for each sensor is included in the Appendices.

2. ORBITIZATION

The orbitization process reorbitizes and reformats multiple input files into an intermediate base file. The base file is a GPM standard orbital file that begins and ends at the southernmost point. It is written in a base format that preserves all of the information from the input but is written out in HDF5.

The purpose of orbitization is to prepare a standard orbital file in the same format for the succeeding L1C intercalibration process. The use of the base file allows the Intercalibration Working Group (X-CAL) to experiment with different intercalibration algorithms without having to read the inputs in several different formats and without having to reorbitize the data.

The orbitization process is needed only when the input files do not conform to the GPM standard orbit format. L1C GMI and L1C TMI processes do not need the orbitization process because their input source files (1BASEGMI and 1BASETMI, respectively) are already GPM standard orbital files. The major components in the orbitization process include orbit boundary derivation and data reorbitization.

2.1 ORBIT BOUNDARY DERIVATION

The orbit start (and end) point is the beginning of scan nearest the instant in time when the satellite reaches the southernmost point in its orbit, independent of where each instrument happens to be pointing at that instant. The southernmost point in orbit was chosen to avoid the undesirable granule boundaries in the tropics, over Japan, and over ground validation (GV) sites (most of which are in the northern hemisphere). The North American Aerospace Defense Command (NORAD) two-line element (TLE) and a simplified General Perturbations Satellite Orbit Model 4 (SGP4) orbital model were used in the L1C process to derive the orbit boundaries [Hoots and Roehrich, 1980].

2.1.1 Two-Line Element (TLE)

A two-line element set is a set of orbital elements that describe the orbit of an Earth satellite. The TLE is in a format specified by NORAD and used by NORAD and the National Aeronautics and Space Administration (NASA). The TLE can be used directly by the SGP4 model to compute the precise position of a satellite at a particular time.

The following is an example of a TLE:

```
1 25544U 98067A   08264.51782528 -.00002182  00000-0 -11606-4 0  2927
2 25544   51.6416 247.4627 0006703 130.5360 325.0288 15.72125391563537
```

The meaning of these data is as follows:

LINE 1

Field	**Columns**	**Content**	**Example**
1	01-01	Line number	1
2	03-07	Satellite number	25544
3	08-08	Classification (U=Unclassified)	U
4	10-11	International designator (last two digits of launch year)	98
5	12-14	International designator (launch number of the year)	067
6	15-17	International designator (piece of the launch)	A
7	19-20	Epoch year (last two digits of the year)	08
8	21-32	Epoch (day of the year and fractional portion of the day)	264.51782528
9	34-43	First time derivative of the mean motion divided by two	-.00002182
10	45-52	Second time derivative of mean motion divided by six (decimal point assumed)	00000-0
11	54-61	B-Star drag term (decimal point assumed)	-11606-4
12	63-63	The number 0 (originally this should have been “ephemeris type”)	0
13	65-68	Element number	292
14	69-69	Checksum (Modulo 10)	7

LINE 2

Field	**Columns**	**Content**	**Example**
1	01-01	Line number	2
2	03-07	Satellite number	25544
3	09-16	Inclination (degrees)	51.6416
4	18-25	Right ascension of the ascending node (degrees)	247.4627
5	27-33	Eccentricity (decimal point assumed)	0006703
6	35-42	Argument of perigee (degrees)	130.5360
7	44-51	Mean anomaly (degrees)	325.0288
8	53-63	Mean motion (revolutions per day)	15.72125391
9	64-68	Revolution number at epoch (revolutions)	56353
10	69-69	Checksum (Modulo 10)	7

2.1.2 SGP4

The Simplified General Perturbations Satellite Orbit Model 4 (SGP4) is a NASA/NORAD algorithm that calculates the orbital state vectors of near-Earth satellites relative to the Earth Centered Inertial coordinate system. TLE data should be used as the input for the SGP4 algorithm. The accuracy of SGP4 is typically about 1 km in position. More details about TLE and SGP4 can be found in Spacetrack Report No. 3 [Hoots and Roehrich, 1980].

2.1.3 Daily Orbit Start/Stop Times Generation

Each day, TLEs for satellites of interest (e.g., F16, F17, F18, NOAA-18, METOP-A, etc.) are obtained automatically from the Spacetrack site and the U.S. Army STRATCOM message system, and the TLE data are stored in the PPS database. The ostFinderTLE algorithm, which utilizes the SGP4 model, then is run using these TLE data. The algorithm computes the satellite positions throughout the day and identifies the orbit start/stop times (orbit definition) by searching the times when the satellite reaches the lowest position (in Z component). It then outputs these orbit start/stop times and orbit numbers to an orbit definition file for each orbit identified during the day. These orbit definition data are then registered in the database and can be used in the succeeding data reorbitization process.

The very first orbit definition is created manually by assigning an initial orbit number. After that, the ostFinderTLE will automatically increment the orbit number by one from the previous orbit definition. This process is done only once per day. Once the orbit definition data are created during the initial processing, they will not change during the reprocessing.

2.2 DATA REORBITIZATION

In most cases, it takes two or three input files to create one GPM standard orbit file. This process is done by the L1CBASE algorithms. The inputs to L1CBASE are: Input filenames, orbitNumber, orbitStartDate, orbitStartTime, orbitStopDate, and orbitStopTime. The output is a standard base file; it is standard in the sense that it has been reorbitized to a GPM standard orbit and reformatted into a common HDF5 format. The base file preserves all information from the input and is used as the input to the succeeding L1C intercalibration algorithms.

The L1CBASE algorithms read multiple input files. For each sensor, the input is in a specific format (binary, NetCDF, HDF, etc.), and therefore different code applying to each format is used to read the input files. The scan time is used to check whether the current scan data fall within the desired L1C orbit boundary and determine whether they should be written to the output file. The algorithm also checks for missing scans and fills in missing data if found. In the case of antenna temperature (Ta) being provided in the input data, the antenna pattern correction (APC) coefficients are applied to convert Ta to brightness temperature (Tb). The APC coefficients and conversion code used are provided from the data source. An empty granule is generated if no scan was extracted from the input files. Scan data are reformatted into the base file format and written to the output base file using the PPS Science Algorithm Input/Output Toolkit (TKIO).

A minimum of processing, other than reorbitizing, reformatting, and Ta to Tb conversion is done in the L1CBASE algorithm. This algorithm simply preserves all information from the input data and creates a uniform, standard base file for further L1C processing. Some additional parameters such as incidence angle, Sun glint angle, solar beta angle, etc. may be computed and output to the base file to support the X-CAL Working Group's intercalibration analysis.

3. SATELLITE INTERCALIBRATION ALGORITHMS

Producing intercalibrated brightness temperature data from different satellites depends on the details of each sensor. The GPM L1C implementation uses GMI as the reference standard.

For each sensor and satellite, an intercalibration table provided by the X-CAL team is implemented in the L1CXCAL algorithm to produce the intercalibrated brightness temperature (Tc). The intercalibration table consists of a series of tie points and offsets for each channel. The table has a generic format: It contains two lines of information for each channel. The first column contains the channel number from 1 to N, and the second column contains the number of tie points for that channel. The remaining values in the first line consist of the temperature values in Kelvin for each tie point, and the second line contains the calibration offset values in Kelvin for each tie point. For a particular channel, the first offset value is used for pixels with Tb less than the first tie point. For pixels with Tb larger than the last tie point, the last offset value is used. And for pixels with Tb between two tie points, an interpolated value from the two corresponding offsets is used. Note that the resulting offset values are added to the Tb so the final intercalibrated brightness temperature is Tc= Tb + offset.

Please see the "Intercalibration of the GPM Microwave Radiometer Constellation" publication [Berg et al., 2016] for the physical and mathematical bases of satellite intercalibration.

4. QUALITY CONTROL

To ensure the consistency among all L1C algorithms, all data are checked and quality flags (QFs) are assigned. L1C quality flags contain two sets of flags. The first set is the generic flags that apply to all sensors, and the second set is the sensor-specific flags that vary from sensor to sensor.

The general specification is as follows:

0	Good data.	
-99	Missing values (no quality information available).	
Positive value	Cautionary warning flags; brightness temperatures are retained.	
	1 – 99	Generic flags for all sensors.
	100 – 127	Sensor-specific flags.
Negative value	Major error flags; brightness temperatures are set to missing values.	
	(-1) – (-98)	Generic flags for all sensors.
	(-100) – (-127)	Sensor-specific flags.

The following generic quality flags are set for data of questionable quality. The corresponding brightness temperatures are retained; however, it is advised to use caution with these values.

0	Good.
1	Possible Sun glint, 0 <= sunGlintAngle < 20 degrees.
2	Possible radio frequency interference.
3	Degraded geolocation data.
4	Data corrected for warm load intrusion.

The following generic quality flags are set for failing catastrophic tests. As a result, in each of these cases the resulting brightness temperatures are set to missing values.

-1	Data are missing from file or are unreadable.
-2	Invalid Tb or nonphysical brightness temperature (Tb < 50K or Tb > 350K).
-3	Error in geolocation data.
-4	Data are missing in one channel.
-5	Data are missing in multiple channels.
-6	Latitude/longitude values are out of range.
-7	Non-normal status modes.
-10	Distance to corresponding LF pixel > 7 km (used in L1C-R product only).

The missing values used in L1C algorithms are as follows:

MISSING_FLOAT	-9999.9
MISSING_DOUBLE	-9999.9
MISSING_INT	-9999
MISSING_SHORT	-9999
MISSING_BYTE	-99

Detailed quality control procedures and sensor-specific quality flags for each radiometer are discussed in the Appendices.

5. ANCILLARY DATA CALCULATIONS

Various geometric ancillary data such as solar beta angle, Earth incidence angle, and Sun glint angle are calculated during the L1C process if the input source does not contain such data. The details can be obtained from the PPS GPM Geolocation Toolkit Algorithm Theoretical Basis Document (ATBD).

6. LEVEL 1C PROCESSING

This section documents the software architecture overview and details for Level 1C processing. Level 1C processing is further divided into three steps: 1) orbit boundaries derivation, 2) data reorbitization, and 3) satellite intercalibration.

Not all sensors require all three steps in their L1C processing. For sensors such as GMI and TMI, the input file is already in GPM standard orbital base file format; therefore, processing steps one and two can be omitted.

6.1 ORBIT BOUNDARIES DERIVATION PROCESSING

Orbit boundaries derivation processing uses the ostFinderTLE algorithm. It generates the daily orbit definition file (also called orbit start/stop times [OST] file) for a given date and satellite. Each orbit definition file contains the start time, stop time, and orbit number information for all orbits in one day. Orbit definition data are then registered in the database and to be used in succeeding data reorbitization processing. This processing is done only once per day for each satellite of interest.

6.1.1 Activation

The scheduler spawns the ostFinderTLE executable once per day for each of the partner satellites. Command line usage:

ostFinderTLE   jobName   inputParameterFile

jobName – A given string assigned to this job.
inputParameterFile – A text file that lists all the input parameters using "key=value" format.

The following is an example of the inputParameterFile:

```
platform=MT1
date=2012-09-10
preorbitnumber=4715
preorbittaistop=810772044.7
outfilename=~jchou/ostXML/MT1/MT1.20120910.V01A.ORBDEF.xml
maxmissingdays=5
outtype=XML
tle1=1 37838U 11058A   12253.88247965 +.00000263 +00000-0 +00000-0 0 0239
tle2=2 37838 019.9744 213.1232 0009138 044.0573 316.0558 14.0969828604711
```

Input parameters:

platform – Satellite ID.
date – Date in YYYY-MM-DD format.
tle1 – Line 1 of the nearest TLE.
tle2 – Line 2 of the nearest TLE.
preorbitnumber – Previous orbit number.
preorbittaistop – Stop time of the previous orbit in TAI format.
outfilename –The output daily orbit definition filename.
maxmissingdays – The number of days allowed for missing TLEs.
outtype – Output type (text or Extensible Markup Language [XML]).

Output files:

The output of ostFinderTLE is the orbit definition file containing all of the orbits found during the given date. Orbit definition file is in XML format and is to be used for registering orbit information in the database. The following is an example of the daily orbit definition file (MT1.20131201.V01A.ORBDEF.xml):


```xml
<?xml version="1.0" encoding="UTF-8"?>

<!--
This is the XML version of the orbit start times file for 2013-12-01.
-->

<ost:orbitStartTimes
 xmlns:ost="ost"
 xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
 xsi:schemaLocation="OST.xsd">

   <orbit platform="MT1" number="11031" action="insert">
     <startTime format="tai">849393336.300000</startTime>
     <stopTime format="tai">849399452.300000</stopTime>
     <longOfMaxLat>63.823701</longOfMaxLat>
     <timeEventFlag>0</timeEventFlag>
     <ephemQualityFlag>0</ephemQualityFlag>
     <meanSolarBetaAngle>-9.997960</meanSolarBetaAngle>
     <longitudeOnEquator>-19.677301</longitudeOnEquator>
     <timeOnEquator format="tai">849394864.219631</timeOnEquator>
     <timeOnEquator format="utc">2013-11-30 23:00:52.219</timeOnEquator>
     <startTimeAdjusted>2013-11-30 22:35:24</startTimeAdjusted>
     <stopTimeAdjusted>2013-12-01 00:17:19</stopTimeAdjusted>
     <dailyNumber>1</dailyNumber>
   </orbit>
   <orbit platform="MT1" number="11032" action="insert">
     <startTime format="tai">849399452.300000</startTime>
     <stopTime format="tai">849405568.300000</stopTime>
     <longOfMaxLat>37.857946</longOfMaxLat>
     <timeEventFlag>0</timeEventFlag>
     <ephemQualityFlag>0</ephemQualityFlag>
     <meanSolarBetaAngle>-9.876040</meanSolarBetaAngle>
     <longitudeOnEquator>-45.656330</longitudeOnEquator>
     <timeOnEquator format="tai">849400980.018973</timeOnEquator>
     <timeOnEquator format="utc">2013-12-01 00:42:48.018</timeOnEquator>
     <startTimeAdjusted>2013-12-01 00:17:20</startTimeAdjusted>
     <stopTimeAdjusted>2013-12-01 01:59:15</stopTimeAdjusted>
     <dailyNumber>2</dailyNumber>
   </orbit>
   <orbit platform="MT1" number="11033" action="insert">
```

```
    <startTime format="tai">849405568.300000</startTime>
    <stopTime format="tai">849411684.300000</stopTime>
    <longOfMaxLat>11.892200</longOfMaxLat>
    <timeEventFlag>0</timeEventFlag>
    <ephemQualityFlag>0</ephemQualityFlag>
    <meanSolarBetaAngle>-9.754979</meanSolarBetaAngle>
    <longitudeOnEquator>-71.635359</longitudeOnEquator>
    <timeOnEquator format="tai">849407095.818508</timeOnEquator>
    <timeOnEquator format="utc">2013-12-01 02:24:43.818</timeOnEquator>
    <startTimeAdjusted>2013-12-01 01:59:16</startTimeAdjusted>
    <stopTimeAdjusted>2013-12-01 03:41:11</stopTimeAdjusted>
    <dailyNumber>3</dailyNumber>
  </orbit>
  <orbit platform="MT1" number="11034" action="insert">
    <startTime format="tai">849411684.300000</startTime>
    <stopTime format="tai">849417799.300000</stopTime>
    <longOfMaxLat>-14.131845</longOfMaxLat>
    <timeEventFlag>0</timeEventFlag>
    <ephemQualityFlag>0</ephemQualityFlag>
    <meanSolarBetaAngle>-9.634772</meanSolarBetaAngle>
    <longitudeOnEquator>-97.614389</longitudeOnEquator>
    <timeOnEquator format="tai">849413211.618235</timeOnEquator>
    <timeOnEquator format="utc">2013-12-01 04:06:39.618</timeOnEquator>
    <startTimeAdjusted>2013-12-01 03:41:12</startTimeAdjusted>
    <stopTimeAdjusted>2013-12-01 05:23:06</stopTimeAdjusted>
    <dailyNumber>4</dailyNumber>
  </orbit>
  <orbit platform="MT1" number="11035" action="insert">
    <startTime format="tai">849417799.300000</startTime>
    <stopTime format="tai">849423915.300000</stopTime>
    <longOfMaxLat>-40.097575</longOfMaxLat>
    <timeEventFlag>0</timeEventFlag>
    <ephemQualityFlag>0</ephemQualityFlag>
    <meanSolarBetaAngle>-9.515421</meanSolarBetaAngle>
    <longitudeOnEquator>-123.593420</longitudeOnEquator>
    <timeOnEquator format="tai">849419327.418155</timeOnEquator>
    <timeOnEquator format="utc">2013-12-01 05:48:35.418</timeOnEquator>
    <startTimeAdjusted>2013-12-01 05:23:07</startTimeAdjusted>
    <stopTimeAdjusted>2013-12-01 07:05:02</stopTimeAdjusted>
    <dailyNumber>5</dailyNumber>
  </orbit>
  :
  :
</ost:orbitStartTimes>
```

6.1.2 Execution

The flow chart for executing the ostFinderTLE program is shown in Figure 1.

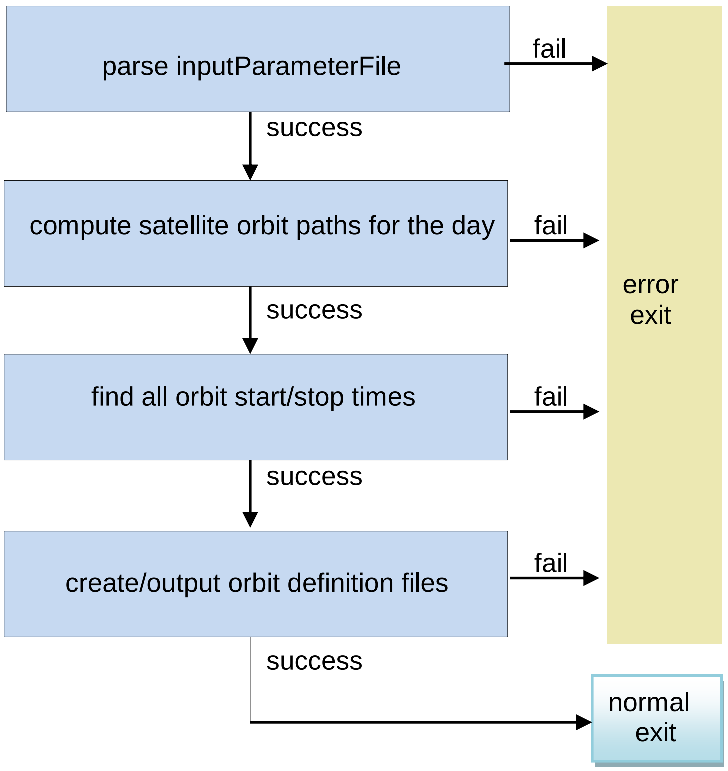

Figure 1. Flow Chart for Executing the ostFinderTLE Program

6.1.3 Termination

When ostFinderTLE finishes execution, successfully or otherwise, it passes a return code to the scheduler and stops. The return code tells the scheduler the reason for termination. The following return states are defined:

- 1 Problem reading input (i.e., no orbit definition file created).
- 2 Problem creating output (i.e., no orbit definition file created).
- 0 Normal termination (i.e., orbit definition files created).

6.2 DATA REORBITIZATION PROCESSING

Data reorbitization processing processes the L1CBASE algorithms. It reorbitizes and reformats multiple input files into one standard GPM base file for each radiometer of interest in the GPM Constellation. Each radiometer has a different executable for the reorbitization processing. Current L1CBASE algorithms include L1CBASEssmis, L1CBASEamsr2, L1CBASEsaphir, L1CBASEatms, and L1CBASEmhs. More will be added when more satellites join the constellation. However, all L1CBASE algorithms follow the same procedure and have the same command line usage.

6.2.1 Activation

The scheduler spawns the L1CBASE program, for example L1CBASEssmis for the SSMI/S sensor, as an autonomous process upon the availability of input granules.

Command line usage:

L1CBASEssmis   jobName   inputParameterFile

jobName – A given string assigned to this job.
inputParameterFile – A text file that lists all the input parameters using “key=value” format.

The following is an example of the inputParameterFile:

```
infile=/SSMIS_TDR/US058SORBRAWspp.tdris_f16_d20121102_s070600_e082800_r46653_cfnoc.raw
infile=/SSMIS_TDR/US058SORBRAWspp.tdris_f16_d20121102_s082400_e104100_r46654_cfnoc.raw
infile=.... (as many as needed to fill an orbit)
outfile=/data/L1Cdata/1Base.F16.SSMIS.TB2014.20121102-S080250-E094445.046652.V00A.HDF5
orbitNumber=46652
platform=F16
ostfile=/ostXML/F16/F16.20121102.V01A.ORBDEF.xml
tle1=1 28054U 03048  A 12307.21145571  .00000105  00000-0  00000+0 0  4386
tle2=2 28054  98.6112 306.6220 0006951 231.8098 128.2996 14.13456952466518
dataPath=/1cXcal/staticFiles/SSMIS/
```

Input parameters:

infile – Input SSMI/S Temperature Data Record (TDR) binary filename.
outfile – Output 1BASESSMIS HDF5 filename.
orbitNumber – Orbit number.
platform – Satellite ID.
ostfile – Daily orbit definition file.
tle1 – Nearest TLE line 1 data.
tle2 – Nearest TLE line 2 data.
datapath – The directory path containing static data needed during processing for SSMI/S.

6.2.2 Execution

The flow chart for executing the L1CBASE program is shown in Figure 2.

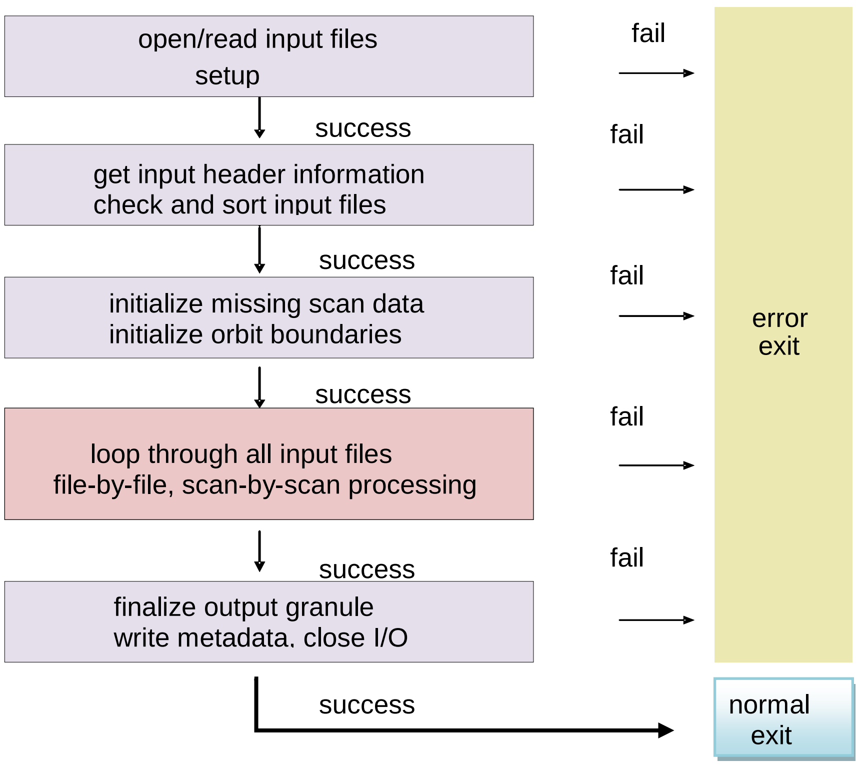

Figure 2. Flow Chart for Executing the L1CBASE Program

The flow chart for executing the file-by-file, scan-by-scan process is shown in Figure 3. If unsuccessful, the program exits with an error report.

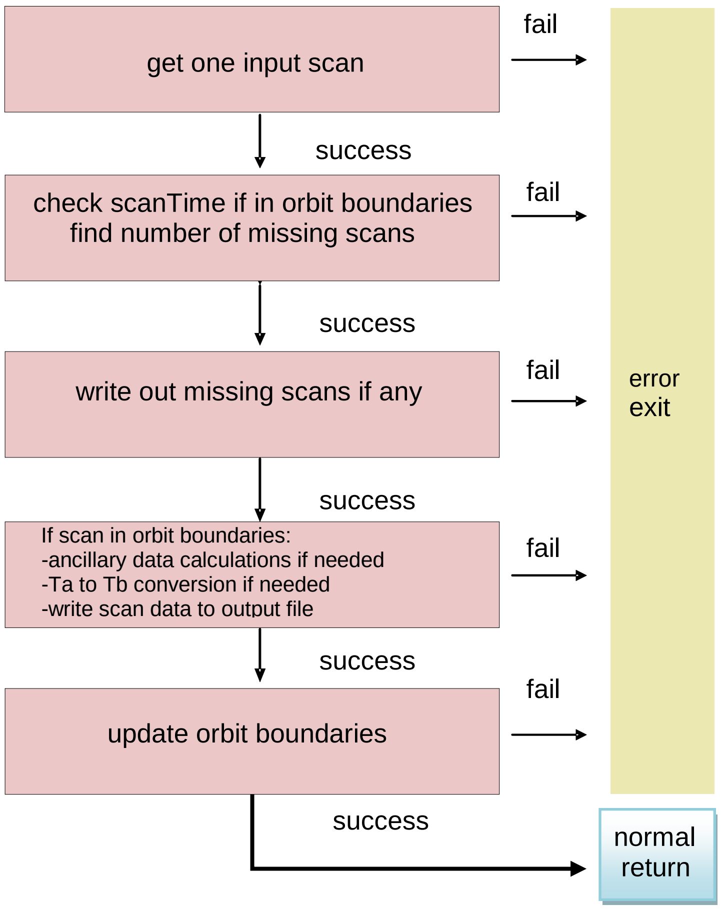

Figure 3. Flow Chart for Executing the L1CBASE File-by-File, Scan-by-Scan Processing

6.2.3 Termination

When L1CBASE finishes execution, successfully or otherwise, it passes a return code to the scheduler and stops. The return code tells the scheduler the reason for termination. The following return states are defined as follows:

0	Normal termination (i.e., L1CBASE created).
99	Empty granule created (i.e., L1CBASE created, but it is an empty granule).
Others	Error termination, program failed.

6.3 INTERCALIBRATION PROCESSING

Intercalibration processing processes the L1CXCAL algorithms. It performs satellite intercalibration and quality control and creates the L1C products for the GPM Core and Constellation satellites. Each sensor has a different executable for the L1C intercalibration processing. Current L1C includes L1CXCALgmi, L1CXCALtmi, L1CXCALssmis, L1CXCALamsr2, L1CXCALsaphir, L1CXCALatms, and L1CXCALmhs. However, all L1CXCAL algorithms follow the same procedure and have the same command usage.

6.3.1 Activation

The scheduler spawns the L1CXCAL program, for example L1CXCALgmi for GMI, as an autonomous process upon the availability of the input 1BASEGMI granule.

Command line usage:

```
L1CXCALgmi  jobName  inputParameterFilename
```

Example of inputParameterFile:

```
infile=1Base.GPM.GMI.TA2014.20140412-S080250-E094445.000652.V00A.HDF5
outfile=1C.GPM.GMI.XCAL2014-N.20140412-S080250-E094445.000652.V00A.HDF5
dataPath=/1cXcal/staticFiles/GMI/
```

Input parameters:

infile – Granule ID of the input base granule.
outfile – Granule ID of the L1C granule that is to contain the output data.
dataPath – Directory path to the static data files needed during processing.

6.3.2 Execution

The flow chart for executing the L1CXCAL program is shown in Figure 4.

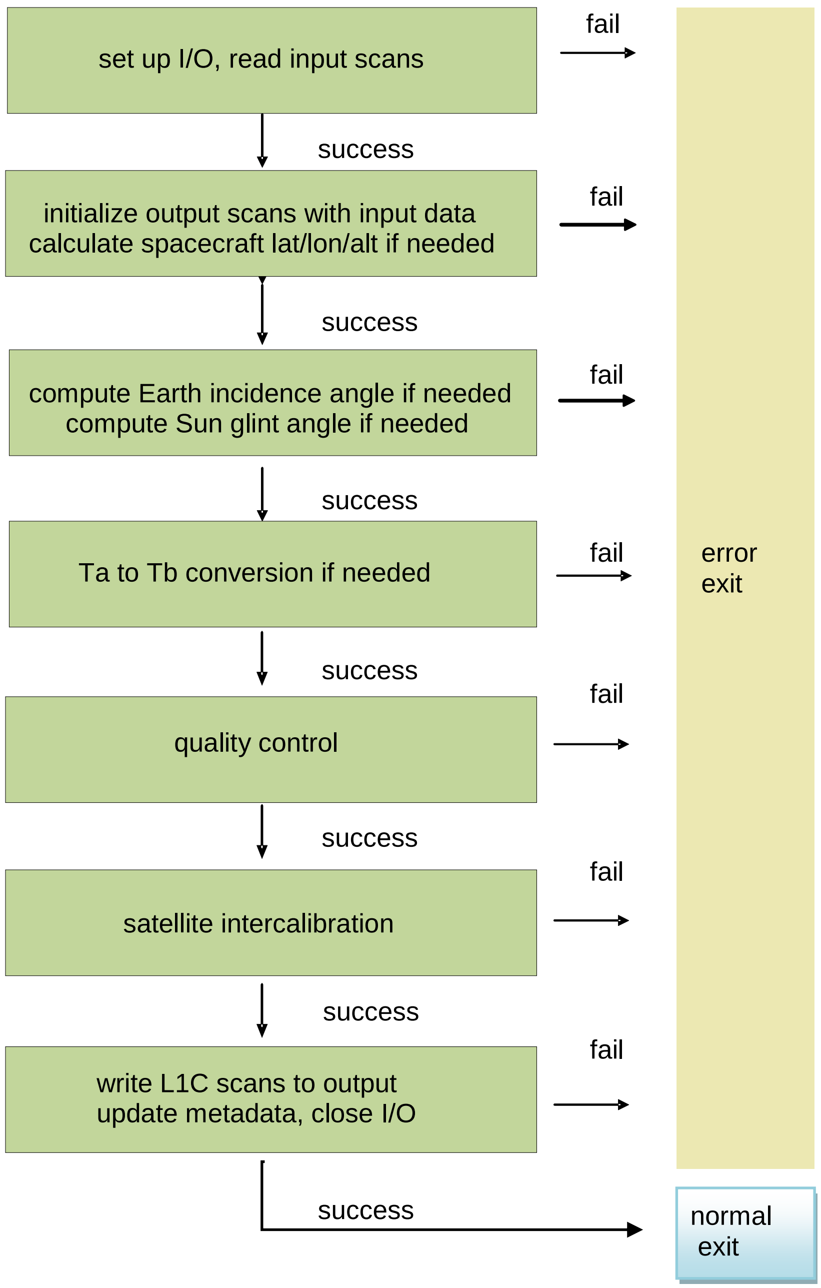

Figure 4. Flow Chart for Executing the L1CXCAL Program

6.3.3 Termination

When L1CXCAL finishes execution, successfully or otherwise, it passes a return code to the scheduler and stops (ceasing to exist as a spawned process). The return code specifies the reason for termination to the scheduler. The following return states are defined:

0	Normal termination (i.e., L1C created).
99	Empty granule created (i.e., L1C created, but it is an empty granule).
Others	Error termination, program failed.

6.3.4 Static Data Files

Various algorithms within the Level 1C intercalibration processing require some parameters. The values are set manually to some initial values (during prelaunch software development) and will possibly be changed by scientists throughout the mission depending on observation of the algorithm performance and external physical changes. A list of these static data files can be obtained in the Appendices for each sensor.

7. REFERENCES

1. Hoots, F. R., and R. L. Roehrich, 1980: Spacetrack Report No. 3, Models for Propagation of NORAD Element Sets, December 1980.
2. Berg, W., S. Bilanow, R. Chen, S. Datta, D. Draper, H. Ebrahimi, S. Farrar, W. Jones, R. Kroodsma, D. McKague, V. Payne, J. Wang, T. Wilheit, and J. Yang, 2016: Intercalibration of the GPM Microwave Radiometer Constellation, J. Atmos. Oceanic Technol., 33, 2639-2654, doi:10.1175/JTECH-D-16-0100.1.

APPENDIX A. L1C GMI

A.1 INTRODUCTION

This section describes sensor-specific information for the Level 1C GPM Microwave Imager (GMI) algorithm.

A.1.1 L1C GMI Input Data Description

The GMI L1C product is derived from GPM 1BASEGMI data. 1BASEGMI contains GMI brightness temperatures (Tb) and is in HDF format. Details about the data content and format can be obtained from the GPM PPS 1BASEGMI File Specification Document. Details of GMI calibration and corrections are documented in the PPS GMI Level 1B (L1B) Algorithm Theoretical Basis Document (ATBD).

A.1.2 L1C GMI Product Description

L1CGMI contains common calibrated brightness temperatures from the GMI passive microwave instrument flown on the GPM satellite. L1CGMI has two swaths. Swath S1 has nine channels that are similar to TRMM TMI (10.65V, 10.65H, 18.7V, 18.7H, 23.8V, 36.64V, 36.64H, 89V, and 89H). Swath S2 has four channels similar to the Advanced Microwave Sounding Unit – B (AMSU-B) (166V, 166H, 183.31+/-3V, and 183.31+/-7V). Data for both swaths are observed in the same revolution of the instrument.

Relation between the swaths: Swath S2 has the same number of scans and the same number of pixels as swath S1. Each S1 scan contains nine channels sampled 221 times along the scan. Each S2 scan contains four channels sampled 221 times along the scan. Since the incidence angle of swath S1 is different than swath S2, the geolocations of the pixel centers are different.

Details about the data content and format can be obtained from the GPM PPS L1C GMI File Specification Document.

A.2 ORBITIZATION

No orbitization process was done to the input source (1BASEGMI) since it is already a GPM orbital base file and contains all the information needed for the satellite intercalibration process.

A.3 SATELLITE INTERCALIBRATION

The GPM GMI brightness temperatures have been defined as the calibration reference for the GPM constellation. As a result, no changes were made to the GMI brightness temperature (Tb).

A.4 QUALITY CONTROL

A.4.1 Quality Control Procedures

The following quality control procedures were implemented for GMI.

Scan-level checking:

1. Scan check for missing scan: Missing scans are flagged, and all parameter values except scanTime are set to missing.
2. Scan check for bad data quality: Scans with dataQuality not equal to 0 are flagged accordingly, and all pixel Tc values are set to missing.

Pixel-level checking:

1. Pixel check for missing Tc: Pixels with missing Tc are flagged, and Tc values are set to missing for that channel.
2. Pixel check for nonphysical Tc: Pixels with brightness temperature values outside the physical limits (currently 50K to 350K) are flagged, and Tc is set to missing for that channel.
3. Pixel check for out-of-range latitude/longitude values: Pixels with latitude/longitude values outside of range (-75 to 75 and -180 to 180) are flagged, and latitude, longitude, and Tc are set to missing.
4. Pixel check for possible Radio Frequency Interference (RFI): Pixels with RFIFlag greater than 0 are flagged as possible RFI warning.
5. Pixel check for possible Sun glint: Pixels with Sun glint angle values greater than or equal to 0 and less than 20.0 degrees are flagged as possible Sun glint warning.
6. Pixel check for blanking: Pixels with sampleHeader.blanking=1 are flagged as blinking warning.

A.4.2 Quality Flag Values and Definition

Generic quality flags:

0 Good.
1 Warning – Possible Sun glint, 0 <= sunGlintAngle < 20 degrees.
2 Warning – Possible radio frequency interference.
3 Warning – Degraded geolocation data.
4 Warning – Data corrected for warm load intrusion.
-1 Error – Data are missing from file or are unreadable.
-2 Error – Invalid Tb or nonphysical brightness temperature (Tb < 50K or Tb > 350K).
-3 Error – Error in geolocation data.
-4 Error – Data are missing in one channel.
-5 Error – Data are missing in multiple channels.
-6 Error – Latitude/longitude values are out of range.
-7 Error – Non-normal status modes.
-10 Distance to corresponding low-frequency (LF) pixel > 7 km (used in L1C-R product only).

Sensor-specific quality flags:

100 Warning – Scan blanking is on.

A.5 STATIC DATA FILES

Table A-1 summarizes the current list of static data files used in the L1CXCALgmi algorithm.

Table A-1. List of Static Data Files for L1C GMI

File Name	Description
1C.GPM.GMI.XCAL2016-C.tbl	Intercalibration Tb offset table

A.6 REFERENCES

1. PPS GPM 1BASEGMI File Specification.
2. PPS GPM L1CGMI File Specification.
3. PPS GPM GMI L1B Algorithm Theoretical Basis Document (ATBD).

APPENDIX B. L1C-R GMI

B.1 INTRODUCTION

This section describes the GPM Level 1C-R GMI algorithm.

B.1.1 L1C-R GMI Input Data Description

The GPM Microwave Imager L1C-R product is derived from GPM L1C GMI data. L1C GMI contains common calibrated brightness temperatures. Details are described in Appendix A.

Two L1C GMI orbits are required to create a L1C-R orbit: A main L1C GMI orbit and its previous or next orbit, depending on the instrument viewing direction.

B.1.2 L1C-R GMI Product Description

L1C-R GMI is a re-mapped/co-registered version of L1C GMI. Its data format is identical to L1C GMI.

L1C-R is the input for the Goddard Profiling Algorithm (GPROF). The L1C-R Swath S1 (Low-Frequency channels) is the same as the L1C Swath S1. However, the L1C-R Swath S2 (High-Frequency [HF] channels) consists of pixels selected from L1C Swath S2 to be as close as possible to the S1 pixels. The L1C-R S2 pixels will often be observed at a different scantime and sometimes from a different orbit than the corresponding S1 pixels. Since L1C S2 is narrower than L1C S1, L1C-R S2 has missing pixels on both edges of the swath.

B.2 CO-REGISTRATION

The L1C GMI Swath S2 (HF channels) scan does not quite match the Swath S1 (LF channels) scan geometry, and the view angle is off by almost 4 degrees. To address this issue, the L1CRgmi algorithm co-registers/collocates the L1C GMI HF field-of-view (FOV) position to bring it as close to the corresponding LF FOV position as possible using the nearest-neighbor matching approach.

Figure B-1 shows the L1C GMI Swath S1 Low-Frequency scan (in color black) and the corresponding Swath S2 High-Frequency scan (in color blue) positions, as well as the resulting matched L1C-R GMI Swath S2 High-Frequency scan (in color red). After the co-registration, the GMI L1C-R HF scan stays close to the corresponding LF scan.

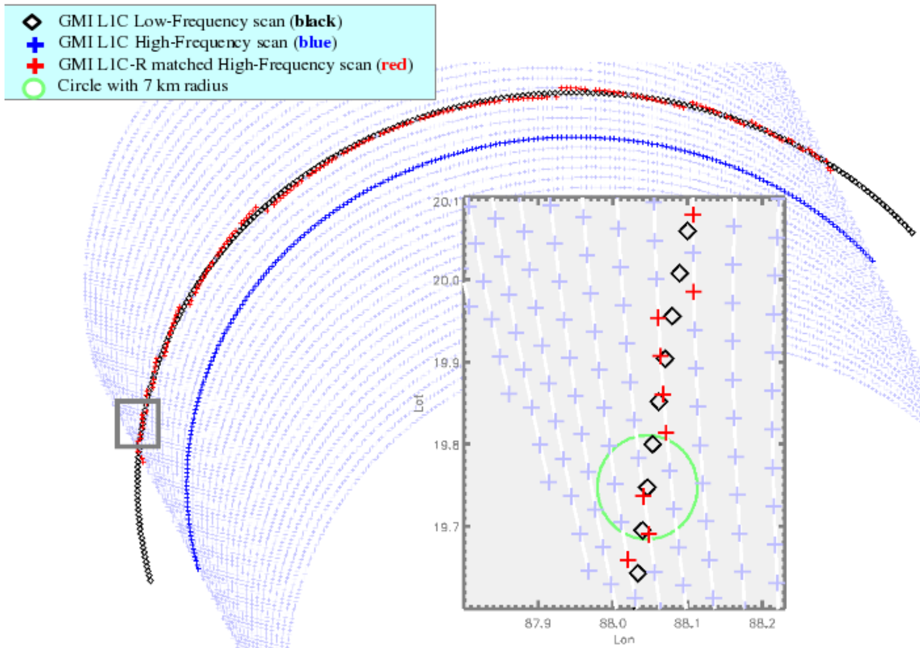

Figure B-1. L1C GMI and L1C-R GMI Swath S1 and S2 Scan Positions

B.2.1 Initial Matching Position

A mean pix/scan offsets table (a function of LF pixel indices) was pre-constructed and used to obtain the initial S2 HF pixel matching position. (This table was provided by Wesley Berg, Colorado State University [CSU].)

For example, a LF pixel at position (pixel, scan)=(p,s), the initial HF matching position (pix0, scan0) will be:

pix0 = p + mean_pixel_offset(p)

scan0 = s + mean_scan_offset(p) if SCorientation=0 (looking forward)

scan0 = s - mean_scan_offset(p) if SCorientation=180 (looking backward)

B.2.2 Nearest-Neighbor Search

For each L1C GMI Swath S1 LF pixel, a nearest-neighbor search is applied on the Swath S2 HF pixels to find its closest match. The searching box is 21 pixels x 11 scans centered at the initial HF matching position obtained from the mean pix/scan offsets table.

Depending on the instrument viewing direction (forward or backward), the searching box may contain HF scans from the next or previous L1C GMI orbit.

If the distance between the LF pixel and the nearest HF pixel found is less than 7km, the nearest HF pixel is selected and its data (Tc, Latitude, Longitude, sunGlintAngle, incidenceAngle, Quality) are used for the L1C-R Swath S2 HF pixel; otherwise, the HF pixel is flagged (S2.Quality=-10 meaning distance to its corresponding LF pixel > 7km) and missing values are output for the L1C-R S2 pixel.

B.3 STATIC DATA FILES

Table B-1 summarizes the current list of static data files used in the L1C-R GMI algorithm.

Table B-1. List of Static Data Files for L1C-R GMI

File Name	Description
indices.list	Mean pix/scan offsets table

B.4 REFERENCE

1. PPS GPM L1CGMI File Specification.

APPENDIX C. L1C TMI

C.1 INTRODUCTION

This section describes sensor-specific information for the GPM Level 1C TRMM Microwave Imager (TMI) algorithm.

C.1.1 L1C TMI Input Data Description

The TMI L1C product is derived from the TRMM 1BASETMI data. 1BASETMI contains both TMI antenna temperatures and radiometric calibrated brightness temperatures (Tb) and is in HDF5 format. Details about the data content and format can be obtained from the GPM PPS 1BASETMI File Specification Document. Details of TMI calibration and corrections are documented in the TRMM TMI L1B Algorithm Theoretical Basis Document (ATBD).

C.1.2 L1C Product Description

L1CTMI contains three swaths of common calibrated brightness temperatures from the TMI passive microwave instrument flown on the TRMM satellite. Swath S1 has two low-resolution channels (10.65V and 10.65H). Swath S2 has five low-resolution channels (19.35V, 19.35H, 21.3V, 37V, and 37H). Swath S3 has two high-resolution channels (85.5V and 85.5H).

Relation between the swaths: Swath S2 has the same number of scans and pixels as Swath S1. Swath S3 has the same number of scans but twice as many pixels as swath S1. Each S1 and S2 scan contains low-frequency channels sampled 104 times along the scan. Each S3 scan contains high-frequency channels sampled 208 times along the scan. S1, S2, and S3 scans are repeated every 1.9s. Along an S1 scan, every other center of an S3 pixel coincides with the center of an S1 pixel.

Details about the data content and format can be obtained from the GPM PPS L1CTMI File Specification Document.

C.2 ORBITIZATION

No orbitization process was done to the input source (1BASETMI) since it is already a GPM orbital base file and contains all the information needed for the satellite intercalibration process.

C.3 SATELLITE INTERCALIBRATION

The calibration adjustments are implemented via piece-wise linear functions with the anchor points contained in 1C.TRMM.TMI.XCAL2017-V.tbl. In most cases, two points are specified so the adjustment is a linear function of the input Tbs. Any positive number of points is possible. If the input Tb is above (below) the highest (lowest) point in the table, then the adjustment for the highest (lowest) point is used. If only one anchor point is given, the adjustment is constant for all Tbs.

C.4 QUALITY CONTROL

C.4.1 Quality Control Procedures

The following quality control procedures were implemented for TMI.

Scan-level checking:

1. Scan check for missing scan: Missing scans are flagged, and all parameter values except scanTime are set to missing.
2. Scan check for bad data quality: Scans with dataQuality not equal to 0 are flagged accordingly (bad geolocation, non-normal mode, or Quality and Accounting Capsule [QAC] error), and all pixel Tc values are set to missing.

Pixel-level checking:

1. Pixel check for missing Tc: Pixels with missing Tc are flagged, and Tc is set to missing for that channel.
2. Pixel check for nonphysical Tc: Pixels with brightness temperature values outside the physical limits (currently 50K to 350K) are flagged, and Tc is set to missing for that channel.
3. Pixel check for out-of-range latitude/longitude values: Pixels with latitude/longitude values outside of range (-45 to 45 and -180 to 180) are flagged, and latitude, longitude, and Tc are set to missing.
4. Pixel check for possible Radio Frequency Interference (RFI): Pixels with RFIFlag greater than 0 are flagged as possible RFI warning.
5. Pixel check for possible Sun glint: Pixels with Sun glint angle values greater than or equal to 0 and less than 20 degrees are flagged as possible Sun glint warning.

C.4.2 Quality Flag Values and Definition

Generic quality flags:

0	Good.
1	Warning – Possible Sun glint, 0 <= sunGlintAngle < 20 degrees.
2	Warning – Possible radio frequency interference.
3	Warning – Degraded geolocation data.
4	Warning – Data corrected for warm load intrusion.
-1	Error – Data are missing from file or are unreadable.
-2	Error – Invalid Tb or nonphysical brightness temperature (Tb < 50K or Tb > 350K).
-3	Error – Error in geolocation data.
-4	Error – Data are missing in one channel.
-5	Error – Data are missing in multiple channels.
-6	Error – Latitude/longitude values are out of range.
-7	Error – Non-normal status modes.

Sensor-specific quality flags:

-100 Error – Quality and Accounting Capsule errors.

C.5 STATIC DATA FILES

Table C-1 summarizes the current list of static data files used in the L1CXCALtmi algorithm.

Table C-1. List of Static Data Files for L1C TMI

File Name	Description
1C.TRMM.TMI.XCAL2017-V.tbl	Intercalibration Tb offset table

C.6 REFERENCES

- PPS GPM 1BASETMI File Specification.
- PPS GPM L1CTMI File Specification.
- PPS TRMM TMI L1B Algorithm Theoretical Basis Document (ATBD).

APPENDIX D. L1C SSMI/S

D.1 INTRODUCTION

This section describes sensor-specific information for the GPM Level 1C Special Sensor Microwave Imager/Sounder (SSMI/S) algorithm.

D.1.1 L1C SSMI/S Input Data Description

The source for the SSMI/S L1C data is the Temperature Data Record (TDR) data produced by the Navy's Fleet Numerical Meteorology and Oceanography Center (FNMOC). The TDR data are archived and publicly available from NOAA's Comprehensive Large Array-Data Stewardship System (CLASS). The TDR data contain antenna temperatures (Ta) and are in binary format. Details about the data content and format can be obtained from the Interface Design Document for the Special Sensor Microwave Imager/Sounder (SSMI/S) Ground Processing Software.

D.1.2 L1C SSMI/S Product Description

L1CSSMIS contains common calibrated brightness temperature from the SSMI/S passive microwave instruments flown on the Defense Meteorological Satellite Program (DMSP) satellites.

Swath S1 has three low-frequency channels (19.35V, 19.35H, and 22.235V). Swath S2 has two low-frequency channels (37V and 37H). Swath S3 has four high-frequency channels (150H, 183.31+/-1H, 183.31+/-3H, and 183.31+/-6.6H). S4 has two high-frequency channels (91.655V and 91.655H). All the above frequencies are in GHz.

Relationships among the swaths: Each S1 and S2 scan contains low-frequency channels sampled 90 times along the scan. Each S3 and S4 scan contains high-frequency channels sampled 180 times along the scan. All four swaths have exactly the same number of scans. All four swaths repeat scans every 1.9s. The Earth positions of S1 are very close to those of S2. The Earth positions of S3 are very close to those of S4. The Earth positions of S1 and S2 alternate with those of S3 and S4 along the satellite track. The positions of the S1 and S2 pixels do not match the positions of the S3 and S4 pixels.

Details about the product content and data format can be obtained from the GPM PPS L1CSSMIS File Specification Document.

D.2 ORBITIZATION

D.2.1 Data Reorbitization

Orbitization processing was first done to the input SSMI/S TDR files to reorbitize and reformat them into the GPM standard orbital base file (1BASESSMIS). Extra ancillary data computed and added to the base file include: solarBetaAngle; timeSinceEclipseEntry; spacecraft latitude, longitude, and altitude; sunGlintAngle; and incidenceAngle. These data are computed based on TLE-derived spacecraft position and velocity.

D.2.2 Corrections Performed by CSU

In this section, all information was provided by Christian Kummerow and Wesley Berg of the Colorado State University. The Fundamental Climate Data Record (FCDR) stewardship code provided by CSU was used to perform SSMI/S geolocation, Ta, and Tb corrections. Additional details can be obtained from the SSMI/S Climate Algorithm Theoretical Basis Document (C-ATBD) and the CSU technical report on Corrections and APC for SSMI/S Ta to Tb [Berg and Sapiano, 2013].

D.2.2.1 Geolocation

The original SSMI/S pixel geolocation is based on predicted spacecraft ephemeris. In L1CSSMIS, the spacecraft ephemeris is recomputed using orbital element information contained in two-line element (TLE) files produced by the North American Aerospace Defense Command (NORAD). Then this updated spacecraft ephemeris is used along with software to re-compute the pixel geolocation based on the geometry of the sensor. Using a previously developed coastline analysis technique, estimates of changes in the spacecraft attitude including deviations in roll, pitch, and yaw have been computed for the life of each of the SSMI/S sensors. Applying these corrections results in an improved pixel geolocation, but more importantly provides accurate estimates of the Earth Incidence Angle (EIA) across the scan and throughout each orbit.

More details on geolocation can be found at the CSU FCDR home page (rain.atmos.colostate.edu/FCDR/index.html) and in the SSMI and SSMI/S Stewardship Code Geolocation Algorithm Theoretical Basis Technical Report [Sapiano, Bilanow, and Berg, 2010].

D.2.2.2 Solar and Lunar Intrusion Correction

Corrections are applied to the Ta to account for solar and lunar intrusions into the warm load and cold-sky mirror. The corrections are based on those applied in the SSMI/S Ground Processing Software Revision 9 (GPSr9) of July 2010.

No solar or lunar intrusion correction is applied to F19 Ta.

D.2.2.3 Cross-Track Bias Correction

The cross-track bias correction is applied to adjust for nonphysical end-of-scan falloff in Ta. An analysis of clear-sky scenes was done for each satellite and channel to determine the magnitude of this falloff. Based on this analysis, a scale factor was computed for each pixel position along the scan, with the center pixel defined as having a multiplier of 1.0. These scale factors are stored in files and used to remove the cross-track biases from the Ta.

For F19 data, the cross-track bias correction is applied to Tb (after the Ta to Tb conversion) instead of Ta.

D.2.2.4 Ta to Tb Conversion

The SSMI/S equivalent channels (19, 22, 37, and 91 GHz channels) have both a cross-polarization and spillover correction applied. For the remaining channels, only the spillover correction is applied.

D.2.2.5 Sun-Angle Correction

A Sun-angle-dependent correction is applied to account for emissive reflector and residual heating issues. Using a double-difference approach, Berg and Sapiano [5] solve for Tb biases as a function of the Sun angle relative to the direction of motion of the spacecraft. Correction maps, or Tb offsets, as a function of Sun azimuth and elevation angles were computed based on matchups with TRMM TMI over the entire available time series for each SSMI/S sensor.

The corrected antenna temperatures (Ta) and brightness temperatures (Tb) are both output to the base file. The resulting 1BASESSMIS file is then used as input to the satellite intercalibration process.

D.3 SATELLITE INTERCALIBRATION

The calibration adjustments are implemented via piece-wise linear functions with the anchor points contained in 1C.DMSP-F*.SSMIS.XCAL2016-V.tbl (* is the F number of the satellite, for example, 18). In most cases, two points are specified so the adjustment is a linear function of the input Tbs. Any positive number of points is possible. If the input Tb is above (below) the highest (lowest) point in the table, then the adjustment for the highest (lowest) point is used. If only one anchor point is given, the adjustment is constant for all Tbs. For the channels at frequencies of 91 GHz and below, two anchor points are used, and for the water vapor sounding channels only a single anchor point is used.

D.4 QUALITY CONTROL

D.4.1 Quality Control Procedures

The following quality control procedures were implemented for SSMI/S. The quality control routines in the CSU FCDR code were used to perform quality control in L1CSSMIS.

1. Check for erroneous pixel geolocation and large variance from climatology (CLIM) for multiple data scans: Affected pixels are flagged, and Ta values are set to missing.
2. Check for known sensor issues: Data are flagged, and Ta is set to missing for known sensor issues as determined from documented issues and data monitoring.
3. Check for nonphysical values: Pixels with Ta outside the physical limits (50K to 350K) are flagged, and Ta is set to missing for that channel.
4. Environmental sensor channels check: For scans where the fraction of pixels with Ta that differ from the mean by more than three standard deviations exceeds a threshold, the data are flagged as having a climatology issue. A warning flag is set for scans near the threshold (within 5%). An error flag is set, and Ta is set to missing for scans exceeding the threshold. Anomalous jumps between adjacent scans are also flagged.

5. Imager channels check: The same check used for environmental sensor channels (19, 22, and 37 GHz) is also applied to the 91 GHz channels.
6. Check for missing scan: Missing scans are flagged, and all parameter values except scanTime are set to missing.
7. Pixel check for out-of-range latitude/longitude values: Pixels with latitude/longitude values outside of range (-90 to 90 and -180 to 180) are flagged, and latitude, longitude, and Tc are set to missing.
8. Check for possible Sun glint: Pixels with Sun glint angle values greater or equal to 0 and less than 20.0 degrees are flagged as possible Sun glint warning.

Additional details are available in the CSU technical report on SSMI and SSMI/S Quality Control [Berg and Rodriguez-Alvarez, 2013].

D.4.2 Quality Flag Values and Definition

Generic quality flags:

0	Good.
1	Warning – Possible Sun glint, 0 <= sunGlintAngle < 20 degrees.
2	Warning – Possible radio frequency interference.
3	Warning – Degraded geolocation data.
4	Warning – Data corrected for warm load intrusion.
-1	Error – Data are missing from file or are unreadable.
-2	Error – Invalid Tb or nonphysical brightness temperature (Tb < 50K or Tb > 350K).
-3	Error – Error in geolocation data.
-4	Error – Data are missing in one channel.
-5	Error – Data are missing in multiple channels.
-6	Error – Latitude/longitude values are out of range.
-7	Error – Non-normal status modes.

Sensor-specific quality flags:

-102	Error – Climatology check flagged in base file.
-110	Error – Climatology check failure (19V channel).
-111	Error – Climatology check failure (19H channel).
-112	Error – Climatology check failure (22V channel).
-113	Error – Climatology check failure (37V channel).
-114	Error – Climatology check failure (37H channel).
-115	Error– Climatology check failure (91V channel).
-116	Error – Climatology check failure (91H channel).
-117	Error – Climatology check failure (150H channel).
-118	Error – Climatology check failure (183+/-1 channel).
-119	Error– Climatology check failure (183+/-3 channel).
-120	Error – Climatology check failure (183+/-7 channel).
-121	Error – Climatology check failure (multiple environment sensor channels).
-122	Error – Climatology check failure (multiple imager sensor channels).
-123	Error – Climatology check failure (one or more Lower Atmosphere Sounding [LAS] channels).

-124 Error – Climatology check failure (one or more Upper Atmosphere Sounding [UAS] channels).
-125 Error – Failure of 150H channel.
-126 Error – Failure of multiple imager sensor channels.
-127 Error – Failure of 37V channel.
102 Warning – Climatology check warning (19V channel).
103 Warning – Climatology check warning (19H channel).
104 Warning – Climatology check warning (22V channel).
105 Warning – Climatology check warning (37V channel).
106 Warning – Climatology check warning (37H channel).
107 Warning – Climatology check warning (91V channel).
108 Warning – Climatology check warning (91H channel).
109 Warning – Climatology check warning (150H channel).
110 Warning – Climatology check warning (183+/-1 channel).
111 Warning – Climatology check warning (183+/-3 channel).
112 Warning – Climatology check warning (183+/-7 channel).
113 Warning – Climatology check warning (multiple environment sensor channels).
114 Warning – Climatology check warning (multiple imager sensor channels).
115 Warning – Climatology check warning (one or more LAS channels).
116 Warning – Climatology check warning (one or more UAS channels).
117 Warning – Correction for lunar intrusion into warm load.
118 Warning – Correction for solar intrusion into warm load.
119 Warning – No sun angle correction in multiple channels.
120 Warning – Sensor data issue warning in multiple imager channels.
121 Warning – Sensor data issue warning in multiple environment channels.
122 Warning – Sensor data issue warning in 91H channel.

D.5 STATIC DATA FILES

Table D-1 summarizes the current list of static data files used in L1CXCALssmis algorithm.

Table D-1. List of Static Data Files for L1C SSMI/S

File Name	Description
CLIM01.grd	Tb climatology file for Jan
CLIM02.grd	Tb climatology file for Feb
CLIM03.grd	Tb climatology file for Mar
CLIM04.grd	Tb climatology file for Apr
CLIM05.grd	Tb climatology file for May
CLIM06.grd	Tb climatology file for June
CLIM07.grd	Tb climatology file for July
CLIM08.grd	Tb climatology file for Aug
CLIM09.grd	Tb climatology file for Sep
CLIM10.grd	Tb climatology file for Oct
CLIM11.grd	Tb climatology file for Nov
CLIM12.grd	Tb climatology file for Dec
geo_LeapSecs.dat	Leap-seconds data
surftag.bin	Surface tag database
Tarm_Template_UPPv3.dat	Emissive antenna correction data
CorCoefs_SSMIS_F16.dat	Spillover and cross-pol coefficients for F16
CorCoefs_SSMIS_F17.dat	Spillover and cross-pol coefficients for F17
CorCoefs_SSMIS_F18.dat	Spillover and cross-pol coefficients for F18
CorCoefs_SSMIS_F19.dat	Spillover and cross-pol coefficients for F19
F16_ctb_may12.dat	Cross-track bias correction coefficients for F16
F17_ctb_may12.dat	Cross-track bias correction coefficients for F17
F18_ctb_may12.dat	Cross-track bias correction coefficients for F18
F19_ctb_feb15.dat	Cross-track bias correction coefficients for F19
F16cal_tsun.dat	Sun correction offsets for F16
F17cal_tsun.dat	Sun correction offsets for F17
F18cal_tsun.dat	Sun correction offsets for F18
F19cal_tsun.dat	Sun correction offsets for F19
geo_ssmis_F16.dat	Geolocation sensor data for F16
geo_ssmis_F17.dat	Geolocation sensor data for F17
geo_ssmis_F18.dat	Geolocation sensor data for F18
geo_ssmis_F19.dat	Geolocation sensor data for F19
Geo_ssmis_F16_rpy.dat	Sensor roll, pitch, yaw data for F16
Geo_ssmis_F17_rpy.dat	Sensor roll, pitch, yaw data for F17
Geo_ssmis_F18_rpy.dat	Sensor roll, pitch, yaw data for F18
Geo_ssmis_F19_rpy.dat	Sensor roll, pitch, yaw data for F19
1C.DMSP-F16.SSMIS.XCAL2016-V.tbl	Intercalibration Tb offset table for F16
1C.DMSP-F17.SSMIS.XCAL2016-V.tbl	Intercalibration Tb offset table for F17
1C.DMSP-F18.SSMIS.XCAL2016-V.tbl	Intercalibration Tb offset table for F18

File Name	Description
1C.DMSP-F19.SSMIS.XCAL2016-V.tbl	Intercalibration Tb offset table for F19

D.6 REFERENCES

1. Interface Design Document for the Special Sensor Microwave Imager/Sounder (SSMI/S) Ground Processing Software.
2. PPS GPM 1BASESSMIS File Specification.
3. PPS GPM L1CSSMIS File Specification.
4. Sapiano, M. R. P., S. Bilanow, and W. Berg, 2010: SSMI and SSMI/S Stewardship Code Geolocation Algorithm Theoretical Basis, Technical Report, Colorado State University.
5. Berg, W., and M. R. P. Sapiano, 2013: Corrections and APC for SSMI/S, Technical Report, Colorado State University.
6. Sapiano, M. R. P., and W. Berg, 2013: Intercalibration of SSMI and SSMI/S for the CSU FCDR, Technical Report, Colorado State University.
7. Berg, W. K., and N. Rodriguez-Alvarez, 2013: SSMI and SSMI/S Quality Control, Technical Report, Colorado State University.
8. SSMI/S Climate Algorithm Theoretical Basis Document (C-ATBD).

APPENDIX E. L1C AMSR2

E.1 INTRODUCTION

This section describes sensor-specific information for the GPM Level 1C Advanced Microwave Scanning Radiometer 2 (AMSR2) algorithm.

E.1.1 L1C AMSR2 Input Data Description

The source for the AMSR2 L1C product is the AMSR2 Level 1B data produced by the Japan Aerospace Exploration Agency (JAXA). The data contain brightness temperatures and are in HDF5 format. Details about the data content and format can be obtained from the AMSR2 Level 1 Product Format Specification Document.

E.1.2 L1C AMSR2 Product Description

L1CAMSR2 contains common calibrated brightness temperature from the AMSR2 passive microwave instrument flown on the Global Change Observation Mission (GCOM-W1) satellite. This product contains six swaths. Swath 1 has channels 10.65V and 10.65H. Swath 2 has channels 18.7V and 18.7H. Swath 3 has channels 23.8V and 23.8H. Swath 4 has channels 36.5V and 36.5H. Swath S5 has two high-frequency A channels (89V and 89H). Swath S6 has two high-frequency B channels (89V and 89H). Data for all six swaths are observed in the same revolution of the instrument. High-frequency A data and high-frequency B data are observed in separate feedhorns.

Relation between the swaths: Each S1 scan contains 10 GHz channels sampled 243 times along the scan. S2, S3, and S4 are sampled nominally at the same position as the S1 samples, but differ by small distances. Each S5 scan contains high-frequency A channels sampled 486 times along the scan. Each S6 scan contains high-frequency B channels sampled 486 times along the scan. Both swath S5 and swath S6 have exactly twice as many pixels as swath S1. S1 pixels 1, 2, 3, ... coincide with S5 pixels 1, 3, 5, ... Scans of all swaths are repeated every 1.5s, and the scans of one swath are about 10km apart along the direction of the satellite track. Along an S1 scan, every other center of an S5 pixel coincides with the center of an S1 pixel, but the S6 pixels are offset from S1 and S5 pixels by nominally 15km in the direction normal to the scan direction on the aft side; in other words, S6 pixels are nominally 15km behind the S1 and S5 pixels for the same scan. Details about the product content and data format can be obtained from the GPM PPS L1CAMSR2 File Specification Document.

E.2 ORBITIZATION

E.2.1 Data Reorbitization

Orbitization processing was first done to the input AMSR2 L1B files to reorbitize and reformat them into the GPM standard orbital base file (1BASEAMSR2). Extra ancillary data computed and added to the base file include: solarBetaAngle; timeSinceEclipseEntry; spacecraft latitude, longitude, and altitude; and sunGlintAngle. Sun glint angle is computed from the input data: Sun_Elevation, Sun_Azimuth, and Earth_Incidence.

E.2.2 Co-registration

During this process, the co-registration parameters are applied to 89 A latitude/longitude values to compute the latitude/longitude for each low-frequency channel using equations documented in the AMSR2 Level 1 Product Format Specification Document 4.1 (57). The computed low-frequency latitude/longitude values are added to the base file. Earth incidence angles for each channel are then computed using each channel's geolocation and added to the base file as well.

The resulting 1BASEAMSR2 file is then used as input to the satellite intercalibration process.

E.3 SATELLITE INTERCALIBRATION

The calibration adjustments are implemented via piece-wise linear functions with the anchor points contained in 1C.GCOMW1.AMSR2.XCAL2016-V.tbl. In most cases, two points are specified so the adjustment is a linear function of the input Tbs. Any positive number of points is possible. If the input Tb is above (below) the highest (lowest) point in the table, then the adjustment for the highest (lowest) point is used. If only one anchor point is given, the adjustment is constant for all Tbs.

E.4 QUALITY CONTROL

E.4.1 Quality Control Procedures

The following quality control procedures were implemented for AMSR2.

Scan-level checking:

1. Scan check for missing scan: Missing scans are flagged, and all parameter values except scanTime are set to missing.

Pixel-level checking:

1. Pixel check for missing Tc: Pixels with missing Tc are flagged, and Tc values are set to missing for that channel.
2. Pixel check for nonphysical Tc: Pixels with brightness temperature values outside the physical limits (currently 50K to 350K) are flagged, and Tc is set to missing for that channel.
3. Pixel check for out-of-range latitude/longitude values: Pixels with latitude/longitude values outside of range (-90 to 90 and -180 to 180) are flagged, and latitude, longitude, and Tc are set to missing.
4. Pixel check for possible Radio Frequency Interference (RFI): Pixels with RFI flag greater than 0 are flagged as possible RFI warning.
5. Pixel check for possible Sun glint: Pixels with Sun glint angle values greater or equal to 0 and less than 20 degrees are flagged as possible Sun glint warning.

E.4.2 Quality Flag Values and Definition

Generic quality flags:

0 Good.
1 Warning – Possible Sun glint, 0 <= sunGlintAngle < 20 degrees.
2 Warning – Possible radio frequency interference.
3 Warning – Degraded geolocation data.
4 Warning – Data corrected for warm load intrusion.
-1 Error – Data are missing from file or are unreadable.
-2 Error – Invalid Tb or nonphysical brightness temperature (Tb < 50K or Tb > 350K).
-3 Error – Error in geolocation data.
-4 Error – Data are missing in one channel.
-5 Error – Data are missing in multiple channels.
-6 Error – Latitude/longitude values are out of range.
-7 Error – Non-normal status modes.

Sensor-specific quality flags:

None.

E.5 STATIC DATA FILES

Table E-1. List of Static Data Files for L1C AMSR2

File Name	Description
1C.GCOMW1.AMSR2.XCAL2016-V.tbl	Intercalibration Tb offset table
amsr2_land_mask.bin	Land water mask
rfiCoeff.txt	Coefficients for RFI index calculation

E.6 REFERENCES

1. AMSR2 Level 1 Product Format Specification.
2. PPS GPM 1BASEAMSR2 File Specification.
3. PPS GPM L1CAMSR2 File Specification.

APPENDIX F. L1C ATMS

F.1 INTRODUCTION

This section describes sensor-specific information for the GPM Level 1C Advanced Technology Microwave Sounder (ATMS) algorithm.

F.1.1 L1C ATMS Input Data Description

The source for the ATMS L1C product is the ATMS Sensor Data Record (SDR) data. The SDR data are archived and publicly available from NOAA's Comprehensive Large Array-Data Stewardship System (CLASS). The data contain brightness temperatures and are in HDF5 format. Details about the data content and format can be obtained from the Joint Polar Satellite System (JPSS) Common Data Format Control Book – External (CDFCD-X) Volume III SDR/TDR Formats.

F.1.2 L1C ATMS Product Description

L1CATMS contains common calibrated brightness temperature from the ATMS passive microwave instrument flown on the Suomi National Polar-orbiting Partnership (NPP) satellite and JPSS satellites. ATMS is approximately a combination of the AMSU-A channels and the MHS channels. ATMS rotates three scans per 8 seconds. ATMS has 22 channels. L1CATMS contains four swaths, one for each band K, A(Ka), W, and G. Swath 1 has channel 23.8QV. Swath 2 has channel 31.4QV. Swath 3 has channel 88.2QV. Swath 4 has six channels (165.5 QH, 183.31+/-7 QH, 183.31+/-4.5 QH, 183.31+/-3 QH, 183.31+/-1.8 QH, and 183.31+/-1 QH). QV means quasi-vertical; the polarization vector is parallel to the scan plane at nadir. QH means quasi-horizontal polarization.

Relationship among the swaths: All four swaths contain observations sampled 96 times along the scan.

Details about the product content and data format can be obtained from the GPM PPS L1CATMS File Specification Document.

F.2 ORBITIZATION

Orbitization processing was first done to the input ATMS SDR files to reorbitize and reformat them into the GPM standard orbital base file (1BASEATMS). Extra ancillary data computed and added to the base file include: solarBetaAngle; timeSinceEclipseEntry; spacecraft latitude, longitude, and altitude; and sunGlintAngle. SunGlintAngle is computed from input SatelliteAzimuthAngle, SatelliteZenithAngle, SolarAzimuthAngle, and SolarZenithAngle data. Earth incidence angles for each band are also computed and added to the base file. The resulting 1BASEATMS file is then used as input to the satellite intercalibration process.

F.3 SATELLITE INTERCALIBRATION

The calibration adjustments are implemented via piece-wise linear functions with the anchor points contained in 1C.NOAA-NPP.ATMS.XCAL2016-V.tbl. In most cases, two points are specified so the adjustment is a linear function of the input Tbs. Any positive number of points is possible. If the input Tb is above (below) the highest (lowest) point, then the adjustment for the highest (lowest) point is used. If only one anchor point is given, the adjustment is constant for all Tbs. For each of the ATMS channels only a single anchor point recalibration is used, i.e., a constant offset.

F.4 QUALITY CONTROL

F.4.1 Quality Control Procedures

The following quality control procedures were implemented for ATMS:

Scan-level checking:

1. Scan check for missing scan: Missing scans are flagged, and all parameter values except scanTime are set to missing.
2. Scan check for time sequence error: Scans with QF19_SCAN_ATMSSDR bit0=1 are flagged, and Tc values are set to missing.
3. Scan check for space view antenna position error: Scans with QF19_SCAN_ATMSSDR bit4=1 are flagged, and Tc values are set to missing.
4. Scan check for blackbody view antenna position error: Scans with QF19_SCAN_ATMSSDR bit5=1 are flagged, and Tc values are set to missing.
5. Scan check for K, Ka, and V bands (KAV) Precision Resistance Thermometer (PRT) error: Scans with QF19_SCAN_ATMSSDR bit2=1 are flagged, and Tc values are set to missing for swaths 1, 2, and 3 (K, A, and V bands).
6. Scan check for W and G bands (WG) PRT error: Scans with QF19_SCAN_ATMSSDR bit3=1 are flagged, and Tc values are set to missing for swaths 4 and 5 (W and G bands).

Pixel-level checking:

1. Pixel check for missing Tc: Pixels with missing Tc are flagged, and Tc values are set to missing for that channel.
2. Pixel check for nonphysical Tc: Pixels with brightness temperature values outside the physical limits (currently 50K to 350K) are flagged, and Tc is set to missing for that channel.
3. Pixel check for out-of-range latitude/longitude values: Pixels with latitude/longitude values outside of range (-90 to 90 and -180 to 180) are flagged, and latitude, longitude, and Tc are set to missing.
4. Pixel check for possible Sun glint: Pixels with Sun glint angle values greater or equal to 0 and less than 20.0 degrees are flagged as possible Sun glint warning.

F.4.2 Quality Flag Values and Definition

Generic quality flags:

0 Good.
1 Warning – Possible Sun glint, 0 <= sunGlintAngle < 20 degrees.
2 Warning – Possible radio frequency interference.
3 Warning – Degraded geolocation data.
4 Warning – Data corrected for warm load intrusion.
-1 Error – Data are missing from file or are unreadable.
-2 Error – Invalid Tb or nonphysical brightness temperature (Tb < 50K or Tb > 350K).
-3 Error – Error in geolocation data.
-4 Error – Data are missing in one channel.
-5 Error – Data are missing in multiple channels.
-6 Error – Latitude/longitude values are out of range.
-7 Error – Non-normal status modes.

Sensor-specific quality flags:

-100 Error – Missing scans indicated by QF19_SCAN_ATMSSDR flag.
-101 Error – Time sequence error.
-102 Error – Insufficient KAV PRT data.
-103 Error – Insufficient WG PRT data.
-104 Error – Space view antenna position error.
-105 Error – Blackbody view antenna position error.

F.5 STATIC DATA FILES

Table F-1. List of Static Data Files for L1C ATMS

File Name	Description
1C.NOAA-NPP.ATMS.XCAL2016-V.tbl	Intercalibration Tb offset table

F.6 REFERENCES

1. Joint Polar Satellite System (JPSS) Common Data Format Control Book – External (CDFCD-X) Volume III SDR/TDR Formats.
2. PPS GPM 1BASEATMS File Specification.
3. PPS GPM L1CATMS File Specification.

APPENDIX G. L1C SAPHIR

G.1 INTRODUCTION

This section describes sensor-specific information for the GPM Level 1C Sondeur Atmospherique du Profil d'Humidite Intertropicale par Radiometrie (SAPHIR) algorithm.

G.1.1 L1C SAPHIR Input Data Description

The source for the SAPHIR L1C product is the SAPHIR L1A data. The data are archived and publicly available from Cloud-Aerosol-Water-Radiation Interactions (ICARE). The L1A data contain brightness temperatures and are in HDF5 format. Details about the data content and format can be obtained from the Megha-Tropiques Level 1 Product Definition Document.

G.1.2 L1C SAPHIR Product Description

1CSAPHIR contains common calibrated brightness temperature from the SAPHIR passive microwave instrument flown on the Megha-Tropiques satellite. Swath S1 is the only swath, and it has six channels (S1, S2, S3, S4, S5, and S6). The channels are 183.31 +/- delta GHz, where delta = 0.2, 1.1, 2.8, 4.2, 6.8, and 11.0.

Relation between the swaths: S1 is the only swath, containing observations sampled 182 times along the scan.

Details about the product content and data format can be obtained from the GPM PPS L1CSAPHIR File Specification Document.

G.2 ORBITIZATION

Orbitization processing was first done to the input SAPHIR L1A files to reorbitize and reformat them into the GPM standard orbital base file (1BASESAPHIR). Extra ancillary data computed and added to the base file include: solarBetaAngle, timeSinceEclipseEntry, spacecraft altitude, and sunGlintAngle. These data are computed based on TLE-derived spacecraft position and velocity. The resulting 1BASESAPHIR file is then used as input to the satellite intercalibration process.

G.3 SATELLITE INTERCALIBRATION

The calibration adjustments are implemented via piece-wise linear functions with the anchor points contained in 1C.MT1.SAPHIR.XCAL2016-V.tbl. In most cases, two points are specified so the adjustment is a linear function of the input Tbs. Any positive number of points is possible. If the input Tb is above (below) the highest (lowest) point, then the adjustment for the highest (lowest) point is used. If only one anchor point is given, the adjustment is constant for all Tbs. For each of the SAPHIR channels only a single anchor point recalibration is used, i.e., a constant offset.

G.4 QUALITY CONTROL

G.4.1 Quality Control Procedures

The following quality control procedures were implemented for SAPHIR.

Scan-level checking:

1. Scan check for missing scan: Missing scans are flagged, and all parameter values except scanTime are set to missing.
2. Scan check for invalid scan: Scans with SAPHIR_QF_SCAN bit15=1 are flagged, and Tc values are set to missing.
3. Scan check for scan error: Scans with SAPHIR_QF_SCAN bit12=1 are flagged, and Tc values are set to missing.
4. Scan check for time error: Scans with SAPHIR_QF_SCAN bit11=1 are flagged, and Tc values are set to missing.
5. Scan check for PRT error: Scans with SAPHIR_QF_SCAN bit10=1 are flagged, and Tc values are set to missing.
6. Scan check for CRC error: Scans with SAPHIR_QF_SCAN bit7=1 are flagged, and Tc values are set to missing.
7. Scan check for payload mode not nominal: Scans with SAPHIR_QF_SCAN bit5=1 or bit4=1 or bit3=1 are flagged, and Tc values are set to missing.
8. Scan check for bad nadir incidence angle: Scans with nadir incidence angle > 1.0 are flagged and Tc values are set to missing.

Pixel-level checking:

1. Pixel check for geolocation error: Pixels with channel QF_samples bit8=1 are flagged, and Tc values are set to missing for all channels.
2. Pixel check for out-of-range latitude/longitude values: Pixels with latitude/longitude values outside of range (-30 to 30 and -180 to 180) are flagged, and latitude, longitude, and Tc are set to missing.
3. Pixel check for channel off: Pixels with channel QF_samples bit11=1 are flagged, and Tc values are set to missing for that channel.
4. Pixel check for invalid or nonphysical Tc: Pixels with brightness temperature values outside the physical limits (currently 50K to 350K) or channel QF_samples bit15=1 are flagged, and Tc is set to missing for that channel.
5. Pixel check for poor L0 count: Pixels with channel QF_samples bit9=1 and bit10=1 are flagged, and Tc values are set to missing for that channel.
6. Pixel check for hot/cold count error: Pixels with channel QF_samples bit4=1 and bit5=1 are flagged, and Tc values are set to missing for that channel.
7. Pixel check for calibration error: Pixels with channel QF_samples bit6=1 or bit7=1 are flagged, and Tc values are set to missing for that channel.
8. Pixel check for possible Sun glint: Pixels with Sun glint angle values greater or equal to 0 and less than 20.0 degrees are flagged as possible Sun glint warning.
9. Pixel check for backward scanning: Pixels with SAPHIR_QF_scan bit3=1 are flagged as backward scanning warning.

G.4.2 Quality Flag Values and Definition

Generic quality flags:

0 Good.
1 Warning – Possible Sun glint, 0 <= sunGlintAngle < 20 degrees.
2 Warning – Possible radio frequency interference.
3 Warning – Degraded geolocation data.
4 Warning – Data corrected for warm load intrusion.
-1 Error – Data are missing from file or are unreadable.
-2 Error – Invalid Tb or nonphysical brightness temperature (Tb < 50K or Tb > 350K).
-3 Error – Error in geolocation data.
-4 Error – Data are missing in one channel.
-5 Error – Data are missing in multiple channels.
-6 Error – Latitude/longitude values are out of range.
-7 Error – Non-normal status modes.

Sensor-specific quality flags:

101 Warning – Backward scanning.
-100 Error – Invalid scan.
-101 Error – Scan error.
-102 Error – Date/time error.
-103 Error – PRT error.
-104 Error – CRC error.
-105 Error – Payload mode not nominal.
-110 Error – Channel is off.
-111 Error – Poor or saturated L0 count.
-112 Error – Hot/cold count not available or error.
-113 Error – Calibration error.

G.5 STATIC DATA FILES

Table G-1. List of Static Data Files for L1C SAPHIR

File Name	Description
1C.MT1.SAPHIR.XCAL2016-V.tbl	Intercalibration Tb offset table

G.6 REFERENCES

1. Megha-Tropiques Level 1 Product Definition Document.
2. PPS GPM 1BASESAPHIR File Specification.
3. PPS GPM L1CSAPHIR File Specification.

APPENDIX H. L1C MHS

H.1 INTRODUCTION

This section describes sensor-specific information for the GPM Level 1C Microwave Humidity Sounder (MHS) algorithm.

H.1.1 L1C MHS Input Data Description

The MHS L1C product is derived from the Microwave Surface and Precipitation Products System (MSPPS) Level-2 MHS orbital products. The data are archived and publicly available from NOAA's Comprehensive Large Array-Data Stewardship System (CLASS). The data contain antenna temperatures (Ta) and are in Hierarchical Data Format-Earth Observing System (HDF-EOS) format. Details about the data content and format can be obtained from the Microwave Surface and Precipitation Products System (MSPPS) Users' Manual (UM).

H.1.2 L1C Product Description

1CMHS contains common calibrated brightness temperature from the MHS passive microwave instrument flown on the NOAA and METOP satellites. Swath S1 is the only swath and has five channels (89V, 157V, 183.31+/-1H, 183.31+/-3H, and 190.31V). MHS is very similar to AMSU-B. The scan period is 2.667s.

Relation between the swaths: S1 is the only swath, containing observations sampled 90 times along the scan.

Details about the data content and format can be obtained from the GPM PPS L1CMHS File Specification Document.

H.2 ORBITIZATION

H.2.1 Data Reorbitization

Orbitization processing was first done to the input MSPPS Level-2 MHS files to reorbitize and reformat them into the GPM standard orbital base file (1BASEMHS). Extra ancillary data computed and added to the base file include: solarBetaAngle; timeSinceEclipseEntry; spacecraft latitude, longitude, and altitude; and sunGlintAngle. These data are computed based on TLE-derived spacecraft position and velocity.

H.2.2 Ta to Tb Conversion

The antenna pattern correction (APC) is based on the ATOVS and AVHRR Processing Package (AAPP) scan-dependent correction algorithm. The algorithm corrects the error due to non-unity antenna reflectivity described in AAPP Documentation Scientific Description (Doc ID: NWPSAF-MF-UD-001, Version: 6.0, Date: June 2006).

The software and look-up tables were provided by the MSPPS group at the NOAA Center for Satellite Applications and Research (STAR). The correction is a linear correction on radiance R.

Rcorr [j][chan] = A[j][chan] *R[j][chan] +B[j][chan]

Where j is the sample number of a scan and chan is the number of channels. A[j][chan] and B[j][chan] are derived from different look-up tables for AMSU-B and MHS sensors onboard NOAA 15-19 and METOP.

Each look-up table contains 270 (90 *3) lines, and each line has five (channels) values (accf[j][chan] for this example).

A[j]=1.0/(accf[j][chan] + accf[90+j][chan]);
B[j][chan]=(-1.0)*(accf[180+j][chan]*Bspace[chan])/(accf[j][chan] + accf[90+j][chan]);

Bspace[chan] are constant fields depending only on channels. Both look-up tables (accf) and values of Bspace are recorded in the base product.

Since the input data contains antenna temperature (Ta) rather than radiance, the correction procedure first converts Ta into radiance using the Planck function, and then applies the correction to the radiance. Last, the code converts the corrected radiance to the brightness temperature (Tb), again using the Planck function. The computed brightness temperature (Tb) values are output to the base file.

The resulting 1BASEMHS file is then used as input to the satellite intercalibration process.

H.3 SATELLITE INTERCALIBRATION

The calibration adjustments are implemented via piece-wise linear functions with the anchor points contained in 1C.*.MHS.XCAL2016-V.tbl (where * indicates NOAA-18, NOAA-19, METOP-A, or METOP-B). In most cases, two points are specified so the adjustment is a linear function of the input Tbs. Any positive number of points is possible. If the input Tb is above (below) the highest (lowest) point, then the adjustment for the highest (lowest) point is used. If only one anchor point is given, the adjustment is constant for all Tbs. For each of the MHS channels only a single anchor point recalibration is used, i.e., a constant offset.

H.4 QUALITY CONTROL

H.4.1 Quality Control Procedures

The following quality control procedures were implemented for MHS.

Scan-level checking:

1. Scan check for missing scan: Missing scans are flagged, and all parameter values except scanTime are set to missing.

Pixel-level checking:

1. Pixel check for missing Tc: Pixels with missing Tc are flagged, and Tc is set to missing for that channel.
2. Pixel check for nonphysical Tc: Pixels with brightness temperature values outside the physical limits (currently 50K to 350K) are flagged, and Tc is set to missing for that channel.
3. Pixel check for out-of-range latitude/longitude values: Pixels with latitude/longitude values outside of range (-90 to 90 and -180 to 180) are flagged, and latitude, longitude, and Tc are set to missing.
4. Pixel check for possible Sun glint: Pixels with Sun glint angle values greater or equal to 0 and less than 20.0 degrees are flagged as possible Sun glint warning.

H.4.2 Quality Flag Values and Definition

Generic quality flags:

0 Good.
1 Warning – Possible Sun glint, 0 <= sunGlintAngle < 20 degrees.
2 Warning – Possible radio frequency interference.
3 Warning – Degraded geolocation data.
4 Warning – Data corrected for warm load intrusion.
-1 Error – Data are missing from file or are unreadable.
-2 Error – Invalid Tb or nonphysical brightness temperature (Tb < 50K or Tb > 350K).
-3 Error – Error in geolocation data.
-4 Error – Data are missing in one channel.
-5 Error – Data are missing in multiple channels.
-6 Error – Latitude/longitude values are out of range.
-7 Error – Non-normal status modes.

Sensor-specific quality flags:

None.

H.5 STATIC DATA FILES

Table H-1 summarizes the current list of static data files used in L1CXCALmhs algorithm.

Table H-1. List of Static Data Files for L1C MHS

File Name	Description
noaa18ac.dat	MHS antenna correction coefficients for NOAA-18
noaa19ac.dat	MHS antenna correction coefficients for NOAA-19
metopAac.dat	MHS antenna correction coefficients for METOP-A
metopBac.dat	MHS antenna correction coefficients for METOP-B
1C.NOAA18.MHS.XCAL2016-V.tbl	Intercalibration Tb offset table for NOAA-18
1C.NOAA19.MHS.XCAL2016-V.tbl	Intercalibration Tb offset table for NOAA-19
1C.METOPA.MHS.XCAL2016-V.tbl	Intercalibration Tb offset table for METOP-A
1C.METOPB.MHS.XCAL2016-V.tbl	Intercalibration Tb offset table for METOP-B

H.6 REFERENCES

1. PPS GPM 1BASEMHS File Specification.
2. PPS GPM L1CMHS File Specification.
3. AAPP Documentation Scientific Description (Doc. ID: NWPSAF-MF-UD-001, Version: 6.0, Date: June 2006.

APPENDIX I. L1C SSMI

I.1 INTRODUCTION

This section describes sensor-specific information for the GPM Level 1C Special Sensor Microwave Imager (SSMI) algorithm.

I.1.1 L1C SSMI Input Data Description

The source for the SSMI L1C product is the Temperature Data Record (TDR) data produced by the Navy's Fleet Numerical Meteorology and Oceanography Center (FNMOC). The TDR data are archived and publicly available from the National Oceanic and Atmospheric Administration's (NOAA's) Comprehensive Large Array-Data Stewardship System (CLASS). The TDR data contain antenna temperatures and are in binary format. Details about the data content and format can be obtained from the Special Sensor Microwave Imager (SSMI) Data Requirements Document (DRD) for the FNMOC.

I.1.2 L1C SSMI Product Description

L1CSSMI contains two swaths of common calibrated brightness temperature from the SSMI passive microwave instruments flown on the Defense Meteorological Satellite Program (DMSP) satellites.

Swath S1 has five low-frequency channels (19.35V, 19.35H, 22.235V, 37V, and 37H). Swath S2 has two high-frequency channels (85.5V and 85.5H). Earth observations for both swaths are taken during a 102.4° segment of the instrument rotation when SSMI is looking in the aft direction from satellite F8 or the forward direction from satellites F10 – F15.

Relation between the swaths: Each S1 scan contains low-frequency channels sampled 64 times along the scan. Each S2 scan contains high-frequency channels sampled 128 times along the scan. Swath S2 has exactly twice as many scans as swath S1. S1 scans 1, 2, 3, ... coincide with S2 scans 1, 3, 5, ... S1 scans are repeated every 3.8s; S2 scans are repeated every 1.9s. Along an S1 scan, every other center of an S2 sample coincides with the center of an S1 sample.

Details about the product content and data format can be obtained from the GPM PPS L1CSSMI File Specification Document.

I.2 ORBITIZATION

I.2.1 Data Reorbitization

Orbitization processing was first done to the input SSMI TDR files to reorbitize and reformat them into the GPM standard orbital base file (1BASESSMI). Extra ancillary data computed and added to the base file include solarBetaAngle; timeSinceEclipseEntry; spacecraft latitude, longitude, and altitude; sunGlintAngle; and incidenceAngle. These data are computed based on TLE-derived spacecraft position and velocity.

I.2.2 Corrections Performed by CSU

In this section, all information was provided by Christian Kummerow and Wesley Berg of the Colorado State University (CSU). The Fundamental Climate Data Record (FCDR) stewardship code provided by CSU was used to perform SSMI geolocation, Ta, and Tb corrections. Additional details can be found at the CSU FCDR home page (rain.atmos.colostate.edu/FCDR/index.html) and the SSMI Climate Algorithm Theoretical Basis Document (C-ATBD).

I.2.2.1 Geolocation

The original SSMI pixel geolocation is based on predicted spacecraft ephemeris. In L1CSSMI, the spacecraft ephemeris is recomputed using orbital element information contained in TLE files produced by the North American Aerospace Defense Command (NORAD). Then this updated spacecraft ephemeris is used along with software to re-compute the pixel geolocation based on the geometry of the sensor. Using a previously developed coastline analysis technique, estimates of changes in the spacecraft attitude including deviations in roll, pitch, and yaw have been computed for the life of each of the SSMI sensors. Applying these corrections results in an improved pixel geolocation, but more importantly provides accurate estimates of the Earth Incidence Angle (EIA) across the scan and throughout each orbit.

More details on geolocation can be found in the SSMI and SSMI/S Stewardship Code Geolocation Algorithm Theoretical Basis Technical Report [Sapiano, Bilanow, and Berg, 2010].

I.2.2.2 Cross-Track Bias Correction

The cross-track bias correction is applied to adjust for nonphysical end-of-scan falloff in Ta. An analysis of clear-sky scenes was done for each satellite and channel to determine the magnitude of this falloff. Based on this analysis, a scale factor was computed for each pixel position along the scan, with the center pixel defined as having a multiplier of 1.0. These scale factors are stored in separate files for each satellite. The cross-track biases are subsequently removed from the Ta by dividing each value by the scale factor correction derived for the given satellite, channel, and pixel position along the scan.

I.2.2.3 Ta to Tb Conversion

Based on a pre-launch analysis of the antenna pattern, described by Colton and Poe (1999), an antenna pattern correction is applied to the observed Ta to calculate the physical Tb.

$$Tb_{v,h} = C_0 * Ta_{v,h}(n) + C_1 * Ta_{h,v}(n) + C_2 * Ta_{v,h}(n-1) + C_3 * Ta_{v,h}(n+1)$$

The coefficient C_1 is multiplied by the cross-polarized pixel, whereas the coefficient C_2 is multiplied by the previous adjacent pixel Ta and the coefficient C_3 by the next adjacent pixel Ta. The coefficient values are stored in a look-up table.

To calculate Tb22v, the above equation requires a Ta22h value, which following Colton and Poe (1999), is obtained by the following:

$Ta_{22H} = 0.653\ Ta_{19H} + 96.6$

While the APC coefficients for each of the six SSMI sensors are provided by Colton and Poe (1999), the decision was made by FNMOC to use the F13 values for F14 and F15 as well for the operational processing of the sensor data record files. While detailed information regarding this decision by FNMOC was not available, CSU chose to be consistent with the SDR record.

I.2.2.4 RADCAL Correction

The activation of radar calibration (RADCAL) suite on F15 in August 2006 caused significant contamination of the 22V channel brightness temperature. This contamination is removed using an approach similar to that of Remote Sensing Systems described in Hilburn (2009) and Hilburn and Wentz (2008).

$Tb22v_{corr} = Tb22v - \text{offset(scan position)} * \text{factor(hotload)}$

where $Tb22v_{corr}$ is the corrected Tb, offset(scan position) and factor(hotload) values were derived by first using a linear regression model to predict Tb22v from the other six channels using 2005 data (before RADCAL activation), non-precipitating ocean scenes (based on the filter developed by Stogryn et al., 1994). The resulting prediction is:

$$Tb22v_{pred} = 0.1444\ Tb19v + 1.1013\ Tb19h + 0.6625\ Tb37v - 1.0975\ Tb37h + 0.0062\ Tb85v + 0.3245\ Tb85h + 3.5265$$

It was then used to predict Tb22v for 2007 data (after RADCAL activation). For each scan position, the mean difference $Tb22v - Tb22v_{pred}$ for 2007 ocean data is stored in a look-up table as offset(scan position).

Simply subtracting this offset from Tb22v results is a reasonable correction for much of the RADCAL-contaminated data, but where the hotload is colder than normal it results in large spikes that indicate a problem with this correction attempt. This is addressed by instead using a multiplicative model as the correction. For 2007 through 2011 data, the values

$(Tb22v - Tb22v_{pred})$ /offset(scan position)

were calculated, then binned as a function of hotload using 1 Kelvin bins. The mean value of each bin is stored in the look-up table as factor(hotload).

The estimated error in $Tb22v_{corr}$ depends on the hotload temperature, varying from around 3.5 K for values above 290 K to over 5 K when the hotload falls below 270 K. These error estimates show that RADCAL-corrected data is not suitable for climate applications.

I.3 SATELLITE INTERCALIBRATION

The calibration adjustments are implemented via piece-wise linear functions with the anchor points contained in 1C.DMSP-F*.SSMI.XCAL2017-V.tbl (* is the F number of the satellite, for example, 13). In most cases, two points are specified so the adjustment is a linear function of the input Tbs. Any positive number of points is possible. If the input Tb is above (below) the highest (lowest) point in the table, then the adjustment for the highest (lowest) point is used. If only one anchor point is given, the adjustment is constant for all Tbs.

I.4 QUALITY CONTROL

I.4.1 Quality Control Procedures

The following quality control procedures were implemented for SSMI. The quality control routines in the CSU FCDR code were used to perform quality control in L1CSSMI.

1. Check for known sensor issues: Data are flagged, and Ta values are set to missing for known sensor issues as determined from documented issues and data monitoring.
2. Check for erroneous spikes in hot and cold loads: Affected data are flagged, count values are reconstructed from Ta values, hot/cold loads are interpolated from neighboring scans, and corrected Ta values are computed.
3. Check for geolocation issues: For data where the original pixel location, given by latitude and longitude, is more than 100 kilometers away from the computed location, the data are flagged and Ta values are set to missing.
4. Scan check for deviations from climatology: Compares the antenna temperatures for each channel along the scan to climatological values. If 25-30% of the pixels along a given scan are outside the range of the mean climatological Ta +/- 3 standard deviations, the scan is flagged as warning. If more than 30% then the scan is flagged and Ta values are set to missing.
5. Pixel check for nonphysical values: Checks that individual Ta values are within physical limits (currently 50K to 325K), that lat/lon values are within range (-90 to 90 and -180 to 180), and that the distance between pixels along a scan is reasonable (10 km to 30 km). Pixels out of the ranges are flagged and Ta values are set to missing.
6. Check for missing scan: Missing scans are flagged and filled with missing values for all parameters except scanTime.
7. Pixel check for possible Sun glint: Checks that individual Sun glint angle values are greater than 20.0 degrees. Pixels with Sun glint angle less than 20.0 degrees are flagged as possible Sun glint.

Additional details are available in the CSU technical report on SSMI and SSMI/S Quality Control [Berg and Rodriguez-Alvarez, 2013].

I.4.2 Quality Flag Values and Definition

Generic quality flags:

0	Good.
1	Warning – Possible Sun glint, 0 <= sunGlintAngle < 20 degrees.
2	Warning – Possible radio frequency interference.
3	Warning – Degraded geolocation data.
4	Warning – Data corrected for warm load intrusion.
-1	Error – Data are missing from file or are unreadable.
-2	Error – Invalid Tb or nonphysical brightness temperature (Tb < 50K or Tb > 350K).
-3	Error – Error in geolocation data.
-4	Error – Data are missing in one channel.
-5	Error – Data are missing in multiple channels.
-6	Error – Latitude/longitude values are out of range.
-7	Error – Non-normal status modes.

Sensor-specific quality flags:

-102	Error – Climatology check flagged in base file.
-103	Error – Climatology check failure (19V channel).
-104	Error – Climatology check failure (19H channel).
-105	Error – Climatology check failure (22V channel).
-106	Error – Climatology check failure (37V channel).
-107	Error – Climatology check failure (37H channel).
-108	Error– Climatology check failure (85V channel).
-109	Error – Climatology check failure (85H channel).
-110	Error – Climatology check failure (multiple low-res channels).
-111	Error – Climatology check failure (multiple high-res channels).
-112	Error – Distance between pixels is nonphysical.
-115	Error – Failure of 85V channel on DMSP F08.
-116	Error – Failure of 85V and increased noise in 85H on DMSP F08.
-117	Error – Failure of both 85V and 85H channels on DMSP F08.
-118	Error – Invalid scan time.
-119	Error – Ta set to missing due to bad cal data.
-120	Error – All data set to missing.

102	Warning – Climatology check warning (19V channel).
103	Warning – Climatology check warning (19H channel).
104	Warning – Climatology check warning (22V channel).
105	Warning – Climatology check warning (37V channel).
106	Warning – Climatology check warning (37H channel).
107	Warning – Climatology check warning (85V channel).
108	Warning – Climatology check warning (85H channel).
109	Warning – Climatology check warning (multiple low-res channels).
110	Warning – Climatology check warning (multiple high-res channels).
111	Warning – Warning adjacent/cross-pol pixel flagged as bad.

112 Warning – Warning of increased noise in 85V channel on DMSP F08.
113 Warning – RADCAL correction applied to Tb22v (do not use for climate).
114 Warning – Ta correction made by eliminating spikes in scan cal data.

I.5 STATIC DATA FILES

Table I-1 summarizes the current list of static data files used in the L1CXCALssmi algorithm.

Table I-1. List of Static Data Files for L1C SSMI

File Name	Description
CLIM01.grd	Tb climatology file for Jan
CLIM02.grd	Tb climatology file for Feb
CLIM03.grd	Tb climatology file for Mar
CLIM04.grd	Tb climatology file for Apr
CLIM05.grd	Tb climatology file for May
CLIM06.grd	Tb climatology file for June
CLIM07.grd	Tb climatology file for July
CLIM08.grd	Tb climatology file for Aug
CLIM09.grd	Tb climatology file for Sep
CLIM10.grd	Tb climatology file for Oct
CLIM11.grd	Tb climatology file for Nov
CLIM12.grd	Tb climatology file for Dec
apc.dat	Antenna pattern correction coefficients
cal.dat	CSU Tb calibration coefficients
F08_ctb.dat	Cross-track bias correction coefficients for F08
F10_ctb.dat	Cross-track bias correction coefficients for F10
F11_ctb.dat	Cross-track bias correction coefficients for F11
F13_ctb.dat	Cross-track bias correction coefficients for F13
F14_ctb.dat	Cross-track bias correction coefficients for F14
F15_ctb.dat	Cross-track bias correction coefficients for F15
geo_LeapSecs.dat	Leap-seconds data
geo_SSMI_F08.dat	Geolocation sensor data for F08
geo_SSMI_F08_rpy.dat	Sensor roll, pitch, yaw data for F08
geo_SSMI_F10.dat	Geolocation sensor data for F10
geo_SSMI_F10_rpy.dat	Sensor roll, pitch, yaw data for F10
geo_SSMI_F11.dat	Geolocation sensor data for F11
geo_SSMI_F11_rpy.dat	Sensor roll, pitch, yaw data for F11
geo_SSMI_F13.dat	Geolocation sensor data for F13
geo_SSMI_F13_rpy.dat	Sensor roll, pitch, yaw data for F13
geo_SSMI_F14.dat	Geolocation sensor data for F14
geo_SSMI_F14_rpy.dat	Sensor roll, pitch, yaw data for F14
geo_SSMI_F15.dat	Geolocation sensor data for F15
geo_SSMI_F15_rpy.dat	Sensor roll, pitch, yaw data for F15
radcal_factors_22v_ocean.dat	Radcal adjustment coefficients for F15 22V
radcal_offsets_22v_ocean.dat	Radcal adjustment coefficients for F15 22V

1C.DMSP-F08.SSMI.XCAL2017-N.tbl	Intercalibration Tb offset table for F08
1C.DMSP-F10.SSMI.XCAL2017-N.tbl	Intercalibration Tb offset table for F10
1C.DMSP-F11.SSMI.XCAL2017-V.tbl	Intercalibration Tb offset table for F11
1C.DMSP-F13.SSMI.XCAL2017-V.tbl	Intercalibration Tb offset table for F13
1C.DMSP-F14.SSMI.XCAL2017-V.tbl	Intercalibration Tb offset table for F14
1C.DMSP-F15.SSMI.XCAL2017-V.tbl	Intercalibration Tb offset table for F15

I.6 REFERENCES

1. Colton, M. C., and Poe, G. A., 1999: Intersensor Calibration of DMSP SSMIs: F8 to F-14, 1987-1997, IEEE Trans. Geosci. Rem. Sens., 37, 418-439.
2. Hilburn, K. A. and Wentz, F. J., 2008: Mitigating the impact of RADCAL beacon contamination on F15 SSMI ocean retrievals, Geophys. Res. Let., 35
3. Hilburn, K., 2009: Including temperature effects in the F15 RADCAL correction, Technical Report 051209, Remote Sensing Systems, http://www.remss.com.
4. Sapiano, M. R. P., S. Bilanow, and W. Berg, 2010: SSMI and SSMI/S Stewardship Code Geolocation Algorithm Theoretical Basis, Technical Report, Colorado State University.
5. Berg, W. K., and N. Rodriguez-Alvarez, 2013: SSMI and SSMI/S Quality Control, Technical Report, Colorado State University.
6. SSMI Climate Algorithm Theoretical Basis Document (C-ATBD), http://rain.atmos.colostate.edu/FCDR/index.html
7. Special Sensor Microwave Imager (SSMI) Data Requirements Document (DRD) for FNOC.
8. PPS GPM 1BASESSMIS File Specification.
9. PPS GPM L1CSSMI File Specification.

APPENDIX J. L1C AMSR-E

J.1 INTRODUCTION

This section describes sensor-specific information for the GPM Level 1C Advanced Microwave Scanning Radiometer – Earth Observing System (AMSR-E) algorithm.

J.1.1 L1C AMSR-E Input Data Description

The source for the AMSR-E L1C product is the AMSR-E Level 1B data produced by the Japan Aerospace Exploration Agency (JAXA). The data contain brightness temperatures and are in HDF format. Details about the data content and format can be obtained from the AMSR-E Level 1 Product Format Description Document.

J.1.2 L1C AMSR-E Product Description

L1CAMSRE contains common calibrated brightness temperature from the AMSR-E passive microwave instrument flown on the AQUA satellite. This product contains six swaths. Swath S1 has channels 10.65V and 10.65H. Swath S2 has channels 18.7V and 18.7H. Swath S3 has channels 23.8V and 23.8H. Swath S4 has channels 36.5V and 36.5H. Swath S5 has two high-frequency A channels (89V and 89H). Swath S6 has two high-frequency B channels (89V and 89H). Data for all six swaths are observed in the same revolution of the instrument. High-frequency A and high-frequency B data are observed in separate feed-horns.

Relation between the swaths: Each S1 scan contains 10 GHz channels sampled 196 times along the scan. S2, S3, and S4 are sampled nominally at the same position as the S1 samples, but differ by small distances. Each S5 scan contains high-frequency A channels sampled 392 times along the scan. Each S6 scan contains high-frequency B channels sampled 392 times along the scan. Both swath S5 and swath S6 have exactly twice as many pixels as swath S1. S1 pixels 1, 2, 3, ... coincide with S5 pixels 1, 3, 5, ... Scans of all swaths are repeated every 1.5s and the scans of one swath are about 10 km apart along the direction of the satellite track. Along an S1 scan, every other center of an S5 pixel coincides with the center of an S1 pixel, but the S6 pixels are offset from S1 and S5 pixels by 15 km in the direction normal to the scan direction on the aft side; in other words, S6 pixels are 15 km "behind" the S1 and S5 pixels for the same scan.

Details about the product content and data format can be obtained from the GPM PPS L1CAMSRE File Specification Document.

J.2 ORBITIZATION

J.2.1 Data Reorbitization

Orbitization processing was first done to the input AMSR-E L1B files to reorbitize and reformat them into the GPM standard orbital base file (1BASEAMSRE). Extra ancillary data computed and added to the base file include solarBetaAngle; timeSinceEclipseEntry; spacecraft latitude, longitude, and altitude; and sunGlintAngle. Sun glint angle is computed from the input data: Sun_Elevation, Sun_Azimuth, and Earth_Incidence.

J.2.2 Co-registration

During this process, the co-registration parameters are applied to 89 A latitude/longitude values to compute the latitude/longitude for each low-frequency channel using equations documented in the AMSR-E Level 1A Product Format Specification Document 2.2 (12). The computed low-frequency latitude/longitude values are added to the base file. Earth incidence angles for each channel are then computed using each channel's geolocation and added to the base file as well. The resulting 1BASEAMSRE file is then used as input to the satellite intercalibration process.

J.3 SATELLITE INTERCALIBRATION

The calibration adjustments are implemented via piece-wise linear functions with the anchor points contained in 1C.AQUA.AMSRE.XCAL2017-V.tbl. In most cases, two points are specified so the adjustment is a linear function of the input Tbs. Any positive number of points is possible. If the input Tb is above (below) the highest (lowest) point in the table, then the adjustment for the highest (lowest) point is used. If only one anchor point is given, the adjustment is constant for all Tbs.

J.4 QUALITY CONTROL

J.4.1 Quality Control Procedures

The following quality control procedures were implemented for AMSR-E.

Scan-level checking:

1. Scan check for missing scan: Missing scans are flagged, and all parameter values except scanTime are set to missing.

Pixel-level checking:

1. Pixel check for missing Tc: Pixels with missing Tc are flagged, and Tc values are set to missing for that channel.
2. Pixel check for nonphysical Tc: Pixels with brightness temperature values outside the physical limits (currently 50K to 350K) are flagged, and Tc is set to missing for that channel.
3. Pixel check for out-of-range latitude/longitude values: Pixels with latitude/longitude values outside of range (-90 to 90 and -180 to 180) are flagged, and latitude, longitude, and Tc are set to missing.
4. Pixel check for possible Sun glint: Pixels with Sun glint angle values greater or equal to 0 and less than 20.0 degrees are flagged as possible Sun glint warning.

J.4.2 Quality Flag Values and Definition

Generic quality flags:

0 Good.
1 Warning – Possible Sun glint, 0 <= sunGlintAngle < 20 degrees.
2 Warning – Possible radio frequency interference.
3 Warning – Degraded geolocation data.
4 Warning – Data corrected for warm load intrusion.
-1 Error – Data are missing from file or are unreadable.
-2 Error – Invalid Tb or nonphysical brightness temperature (Tb < 50K or Tb > 350K).
-3 Error – Error in geolocation data.
-4 Error – Data are missing in one channel.
-5 Error – Data are missing in multiple channels.
-6 Error – Latitude/longitude values are out of range.
-7 Error – Non-normal status modes.

Sensor-specific quality flags:

None.

J.5 STATIC DATA FILES

Table J-1 summarizes the current list of static data files used in L1CXCALamsre algorithm.

Table J-1. List of Static Data Files for L1C AMSR-E

File Name	Description
1C.AQUA.AMSRE.XCAL2017-V.tbl	Intercalibration Tb offset table

J.6 REFERENCES

1. AMSR-E Level 1 Product Format Description Document.
2. PPS GPM 1BASEAMSRE File Specification.
3. PPS GPM L1CAMSRE File Specification.

APPENDIX K. L1C AMSU-B

K.1 INTRODUCTION

This section describes sensor-specific information for the GPM Level 1C Advanced Microwave Sounding Unit – B (AMSU-B) algorithm.

K.1.1 L1C AMSU-B Input Data Description

The AMSU-B L1C product is derived from the Microwave Surface and Precipitation Products System (MSPPS) Level-2 AMSU-B orbital products. The data are archived and publicly available from NOAA's Comprehensive Large Array-Data Stewardship System (CLASS). The data contain antenna temperatures (Ta) and are in HDF-EOS format. Details about the data content and format can be obtained from the Microwave Surface and Precipitation Products System (MSPPS) Users' Manual (UM).

K.1.2 L1C Product Description

1CAMSUB contains common calibrated brightness temperature from the AMSU-B passive microwave instrument flown on the NOAA satellites. Swath S1 is the only swath and has five channels: 89.0+/-0.9 GHz, 150.0+/-0.9 GHz, 183.31+/-1 GHz, 183.31+/-3 GHz, and 183.31+/-7 GHz.

Relation between the swaths: S1 is the only swath, containing observations sampled 90 times along the scan. The scan period is 2.667s.

Details about the data content and format can be obtained from the GPM PPS L1CMHS File Specification Document.

K.2 ORBITIZATION

K.2.1 Data Reorbitization

Orbitization processing was first done to the input MSPPS Level-2 AMSU-B files to reorbitize and reformat them into the GPM standard orbital base file (1BASEAMSUB). Extra ancillary data computed and added to the base file include solarBetaAngle; timeSinceEclipseEntry; spacecraft latitude, longitude, and altitude; and sunGlintAngle. These data are computed based on TLE-derived spacecraft position and velocity.

K.2.2 Ta to Tb Conversion

The antenna pattern correction (APC) is based on the AAPP (ATOVS and AVHRR Processing Package) scan-dependent correction algorithm. The algorithm corrects the error due to non-unity antenna reflectivity described in AAPP Documentation Scientific Description (Doc ID: NWPSAF-MF-UD-001, Version: 6.0, Date: June 2006).

The software and look-up tables were provided by the MSPPS group at the NOAA Center for Satellite Applications and Research (STAR). The correction is a linear correction on radiance R.

Rcorr [j][chan] = A[j][chan] *R[j][chan] +B[j][chan]

Where j is the sample number of a scan and chan is the number of channels. A[j][chan] and B[j][chan] are derived from different look-up tables for AMSU-B and MHS sensors onboard NOAA 15-19 and METOP.

Each look-up table contains 270 (90 *3) lines, and each line has five (channels) values (accf[j][chan] for this example).

A[j]=1.0/(accf[j][chan] + accf[90+j][chan]);
B[j][chan]=(-1.0)*(accf[180+j][chan]*Bspace[chan])/(accf[j][chan] + accf[90+j][chan]);

Bspace[chan] are constant fields depending only on channels. Both look-up tables (accf) and values of Bspace are recorded in the base product.

Since the input data contain antenna temperature (Ta) rather than radiance, the correction procedure first converts Ta into radiance using the Planck function, and then applies the correction to the radiance. Last, the code converts the corrected radiance to the brightness temperature (Tb), again using the Planck function. The computed brightness temperature (Tb) values are output to the base file.

The resulting 1BASEAMSUB file is then used as input to the satellite intercalibration process.

K.3 SATELLITE INTERCALIBRATION

The calibration adjustments are implemented via piece-wise linear functions with the anchor points contained in 1C.*.AMSUB.XCAL2017-V.tbl (where * indicates NOAA-15, NOAA-16, or NOAA-17). In most cases, two points are specified so the adjustment is a linear function of the input Tbs. Any positive number of points is possible. If the input Tb is above (below) the highest (lowest) point, then the adjustment for the highest (lowest) point is used. If only one anchor point is given, the adjustment is constant for all Tbs. For each of the AMSU-B channels only a single anchor point recalibration is used, i.e., a constant offset.

K.4 QUALITY CONTROL

K.4.1 Quality Control Procedures

The following quality control procedures were implemented for AMSU-B.

Sensor data issues:

Based on the X-CAL team’s analysis, the 183 +/- 3 GHz channel on NOAA-15 was especially problematic over the entire data record. We do not consider this channel to be useful for any application. Both NOAA-15 and NOAA-16 also had severe degradation starting in 2008 for all three of the NOAA-16 183 GHz channels and in 2009 for NOAA-15 89 GHz, 183 +/- 1 GHz, and 183 +/- 7 GHz channels. As a result, the following data were flagged as missing in the L1C data:

NOAA-15 89 GHz	2009-01-01 to the end.
NOAA-15 183 +/- 1 GHz	2009-01-01 to the end.
NOAA-15 183 +/-3 GHz	Entire data record.
NOAA-15 183 +/-7 GHz	2009-01-01 to the end.
NOAA-16 183 +/-1 GHz	2008-01-01 to the end.
NOAA-16 183 +/-3 GHz	2008-01-01 to the end.
NOAA-16 183 +/-7 GHz	2008-01-01 to the end.

Scan-level checking:

1. Scan check for missing scan: Missing scans are flagged, and all parameter values except scanTime are set to missing.

Pixel-level checking:

1. Pixel check for missing Tc: Pixels with missing Tc are flagged, and Tc is set to missing for that channel.
2. Pixel check for nonphysical Tc: Pixels with brightness temperature values outside the physical limits (currently 50K to 350K) are flagged, and Tc is set to missing for that channel.
3. Pixel check for out-of-range latitude/longitude values: Pixels with latitude/longitude values outside of range (-90 to 90 and -180 to 180) are flagged, and latitude, longitude, and Tc are set to missing.
4. Pixel check for possible Sun glint: Pixels with Sun glint angle values greater or equal to 0 and less than 20.0 degrees are flagged as possible Sun glint warning.

K.4.2 <u>Quality Flag Values and Definition</u>

Generic quality flags:

0	Good.
1	Warning – Possible Sun glint, 0 <= sunGlintAngle < 20 degrees.
2	Warning – Possible radio frequency interference.
3	Warning – Degraded geolocation data.
4	Warning – Data corrected for warm load intrusion.
-1	Error – Data are missing from file or are unreadable.
-2	Error – Invalid Tb or nonphysical brightness temperature (Tb < 50K or Tb > 350K).
-3	Error – Error in geolocation data.
-4	Error – Data are missing in one channel.
-5	Error – Data are missing in multiple channels.
-6	Error – Latitude/longitude values are out of range.
-7	Error – Non-normal status modes.

Sensor-specific quality flags:

-100 – Data are not useable in 89 GHz channel.
-101 – Data are not useable in 150 GHz channel.
-102 – Data are not useable in 183 +/-1 GHz channel.
-103 – Data are not useable in 183 +/-3 GHz channel.
-104 – Data are not useable in 183 +/-7 GHz channel.
-105 – Data are not useable in multiple channels.

K.5 STATIC DATA FILES

Table K-1 summarizes the current list of static data files used in L1CXCALamsub algorithm.

Table K-1. List of Static Data Files for L1C AMSU-B

File Name	Description
noaa15ac.dat	AMSU-B antenna correction coefficients for NOAA-15
noaa16ac.dat	AMSU-B antenna correction coefficients for NOAA-16
noaa17ac.dat	AMSU-B antenna correction coefficients for NOAA-17
1C.NOAA15AMSUB.XCAL2017-V.tbl	Intercalibration Tb offset table for NOAA-15
1C.NOAA16.AMSUB.XCAL2017-V.tbl	Intercalibration Tb offset table for NOAA-16
1C.NOAA17.AMSUB.XCAL2017-V.tbl	Intercalibration Tb offset table for NOAA-17

K.6 REFERENCES

1. PPS GPM 1BASEAMSUB File Specification.
2. PPS GPM L1CMHS File Specification.
3. Microwave Surface and Precipitation Products System (MSPPS) Users’ Manual (UM).
4. AAPP Documentation Scientific Description (Doc ID: NWPSAF-MF-UD-001, Version: 6.0, Date: June 2006).

APPENDIX L. CHANGES FROM VERSION 03 TO VERSION 04

This Version 04 (V04) release involves the following significant changes from the previous release in the calibration of the GPM radiometer constellation.

1. The Level 1C brightness temperature (Tb) data for all of the constellation radiometers has been intercalibrated to be consistent with the Tb from GMI onboard the GPM core satellite. Note that the GMI V04 calibration differs from V03 by up to 2-3 K (based on mean Tb values) for some channels due to updated spillover corrections derived from on-orbit calibration maneuvers.

   V04 Tb changes vary from channel to channel and are functions of brightness temperatures. For channels 1-5, Tb reduced ~3-6 K at their maximums. For channels 10-13, Tb increased ~2-4 K at their maximums. For channels 6-9, Tb increased ~0.1 K at their maximums. Please see the latest GMIL1B ATBD for more details on the GMI V04 calibration updates.

   Comparisons with other well-calibrated radiometers and with radiative transfer simulations indicate that GMI is extremely well calibrated and stable with an absolute calibration accuracy of well within 1 K for all channels.

2. For the constellation radiometers, V04 moves from the use of TRMM TMI and METOP-A MHS as the calibration reference for the window and sounder channels, respectively, to GPM GMI as the reference for all channels. This results in changes to the Level 1C Tb by up to 2.5 K depending on the channel, but with significantly improved consistency between channels and with radiative transfer models. In addition, a number of calibration biases and artifacts have been identified and removed from the Level 1C Tb for the constellation radiometers. These include, but are not limited to, issues such as emissive reflectors, solar and lunar intrusions, and biases across the scan.

3. A bug fix that affects sunGlintAngle calculation was implemented in December 2014 for V03C processing. V03 data generated prior to December 2014 may have sunGlintAngle error up to 6 degrees.

APPENDIX M. CHANGES FROM VERSION 04 TO VERSION 05

This Version (V05) release involves the following changes from the previous release in the calibration of the GPM radiometer constellation.

1. Level 1C GMI V05 brightness temperature (Tc) differs from V04 by as much as -1.4 K for some channels (Figure M-1) due to the following calibration adjustments implemented in V05 GMI L1B/Base:

- Adjusted spillover coefficients. This adjustment is based on the data from GMI deep-space maneuver, inertial hold, and refinements of the analysis performed by the GMI manufacturer and the GPM Intercalibration Working Group (X-CAL). Tc changes vary from channel to channel and are functions of brightness temperatures. For channels 1-5, the maximum change is around -1.0 K. For other channels, Tc changes are minor.
- Adjusted cold load temperature for 10 GHz channels. This is a minor adjustment, and the maximum impact is less than 0.2 K for 10 GHz channels.
- Added a count (Earth and cold) adjustment in the magnetism correction equation. This is a minor adjustment, and the maximum impact is less than 0.2 K.
- Adjusted magnetic correction coefficients. This is also a minor adjustment, and the maximum impact is less than 0.2 K.
- Added Earth-view antenna-induced along-scan corrections. The correction is less than 0.1 K for most pixels along a scan but can be as large as 0.5 K near the edge of scans.

For more details on the GMI V05 calibration updates, please see the latest GMI Level 1B ATBD.

Figure M-1 (next page) shows the monthly density plot of the GMI Tc difference between V05 and V04.

2. For the constellation radiometers, the Level 1C brightness temperature (Tc) data has been intercalibrated to be consistent with the V05 GMI brightness temperature. As a result, V05 AMSR2 Tc decreased 0 to 1.2 K depending on the channel and brightness temperature, ATMS decreased 0 to 0.77 K, MHS decreased 0 to 0.2 K, SSMI/S decreased 0 to 1.05 K, and SAPHIR decreased 0.07 to 0.08 K.

3. Due to a sensor issue, SSMI/S F17 37V channel data has been flagged and set to missing during the following periods:

   2016-04-05 to 2016-05-18 (orbits 48595 to 49202)
   2016-08-03 to present (orbits 50286 onward)

4. SSMI/S F17 37H channel Tc was affected by 37V missing data. Daily mean Tc dropped 2-4 K due to lack of cross-pol correction. This issue has been corrected in V05.

5. A small bug in SSMI/S 22V cross-pol correction has been fixed. Only a few pixels with missing 19V and/or 19H data were affected.

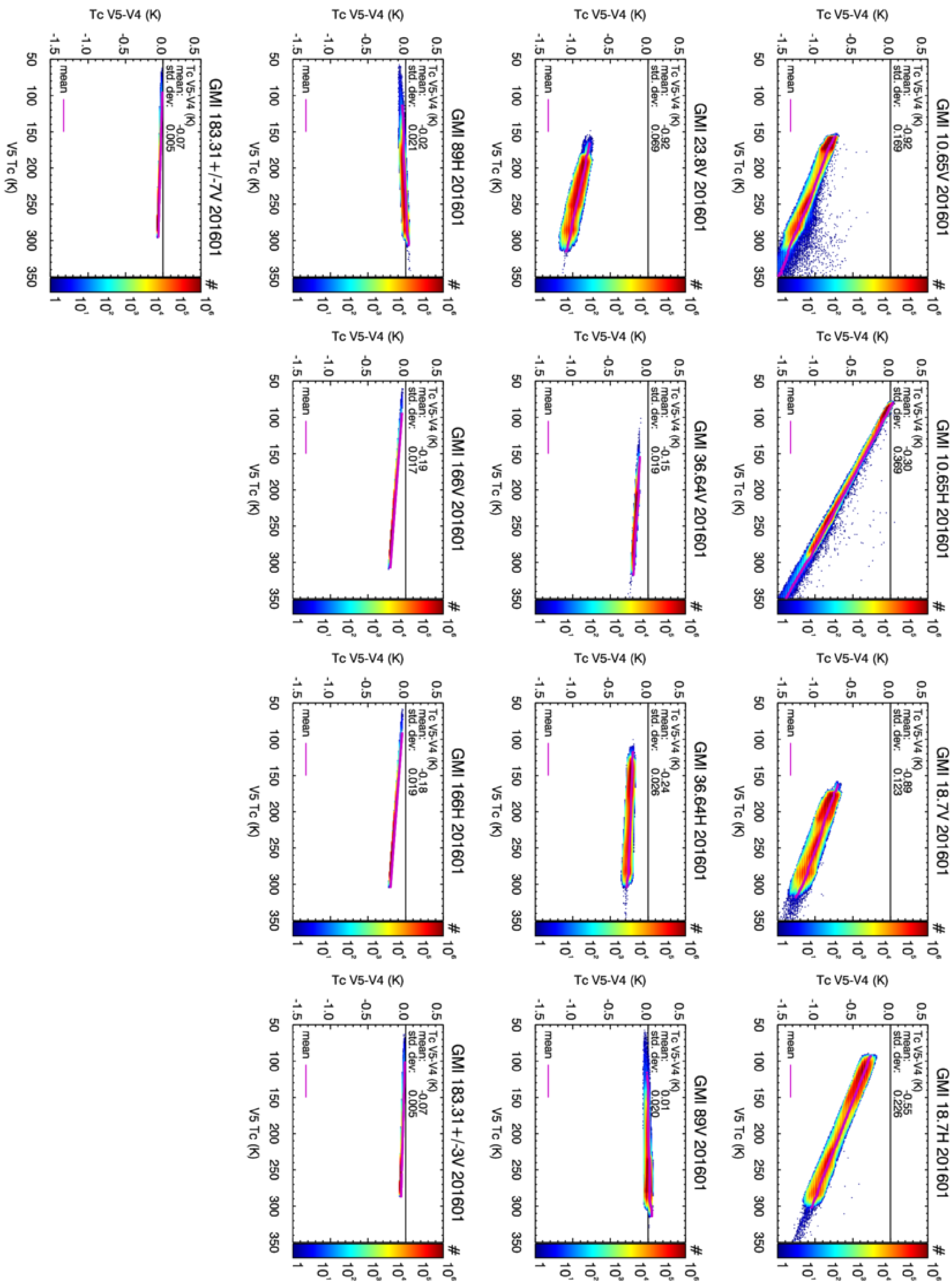

Figure M-1. Monthly Density Plot of L1C GMI Tc Difference Between V05 and V04

APPENDIX N. TRMM V8 CHANGES

Tropical Rainfall Measuring Mission (TRMM) Version 8 (V8) fully incorporates TRMM data into Global Precipitation Measurement (GPM) data processing. TRMM and constellation products become part of the GPM data suite. Products are all in GPM HDF5 format and are labeled with product version V05.

1. TRMM V8 Level 1C TRMM Microwave Imager (TMI) brightness temperature (Tc) differs from TRMM V7 by as much as 2.3 K for some channels (see Figure N-1) due to the following changes:

   A. Improvements implemented in the V8 TMI L1B/1Base level:
      - Adjusted TMI APC. This adjustment is the major improvement from V7 to V8 in TMI antenna pattern correction. The adjustment is based on the data from TMI deep space and other special calibration maneuvers, and refinements of the analysis from the GPM Intercalibration Working Group (X-CAL).
      - Added TMI emissive antenna correction to replace the V7 empirical warm correction. The adjustment is based on reflector emissivities as a function of frequency derived using the data from TMI deep space and other special calibration maneuvers, derived reflector physical temperatures, and refinements of the analysis from the X-CAL team.
      - Used multiple scan calibration averaging to replace the V7 single scan calibration.
      - Added correction on warm intrusions (Moon and RFI) onto cold load and Sun intrusions onto the hot load.
      - Updates to the TRMM spacecraft attitude.
      - Updated view-angle offsets for the TMI feedhorns based on geolocation analysis for more accurate pointing information by channel.
      - Updated the cross-scan bias corrections to account for scene temperature dependent differences based on an analysis over both cold (ocean) and warm (land) scenes.

   B. In addition to the L1B/1Base level Tb changes, TRMM V8 Level 1C TMI brightness temperature (Tc) has been intercalibrated to be consistent with the V05 GPM Microwave Imager (GMI) brightness temperature. The V7 TMI Tc had no intercalibration applied.

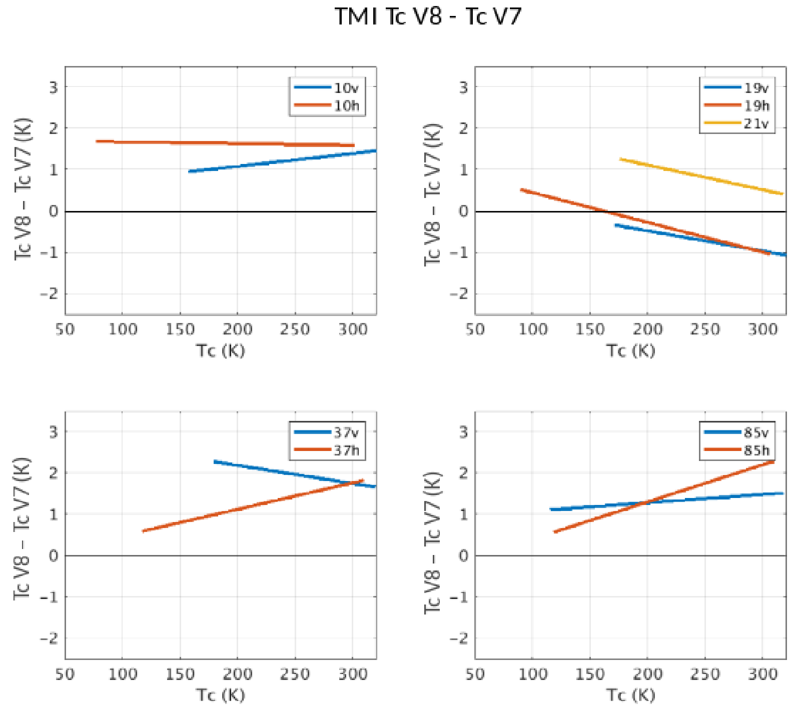

Figure N-1. TMI L1C Mean Tc Differences Between V8 and V7 (January 2014)

2. TRMM V8 Level 1C TMI brightness temperature (also known as GPM V05 Tc) differs from GPM V04 1C TMI Tc by as much as 1.2 K at the cold end and -1.6 K at the warm end for some channels (see Figure N-2) due to the following changes:

   A. Same improvements as described in 1.A.

   B. TRMM V8 (or GPM V05) TMI Tc has been intercalibrated to be consistent with the V05 GMI brightness temperature, while GPM V04 TMI Tc was intercalibrated to V04 GPM GMI brightness temperature.

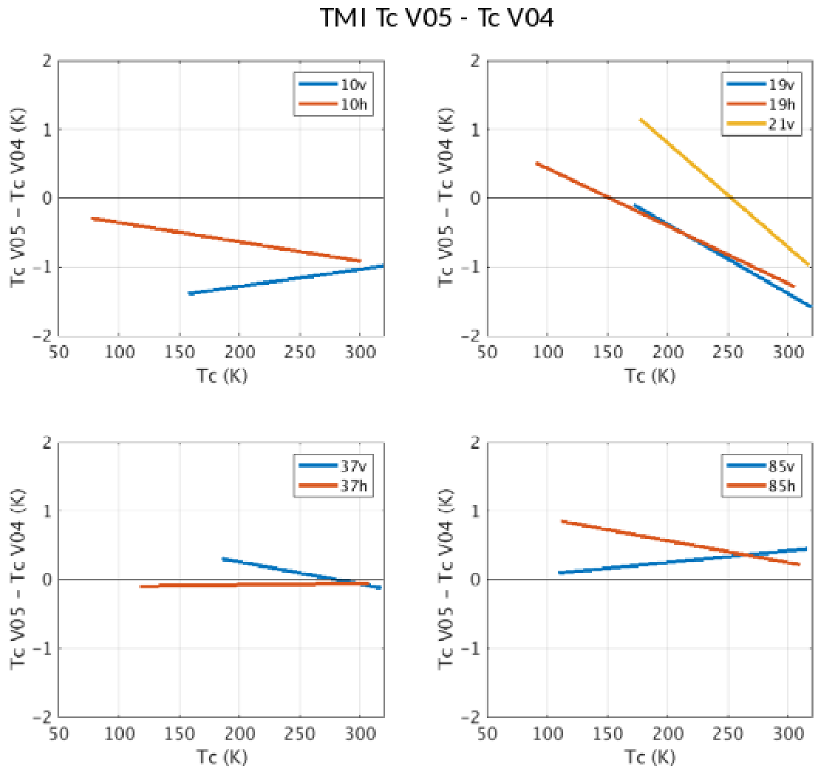

Figure N-2. TMI L1C Mean Tc Differences Between V05 and V04 (March 2014)

3. For all partner radiometers, the Level 1C brightness temperature (Tc) data has been intercalibrated to be consistent with the V05 GMI brightness temperature. See Figure N-3 for TRMM constellation data availability.

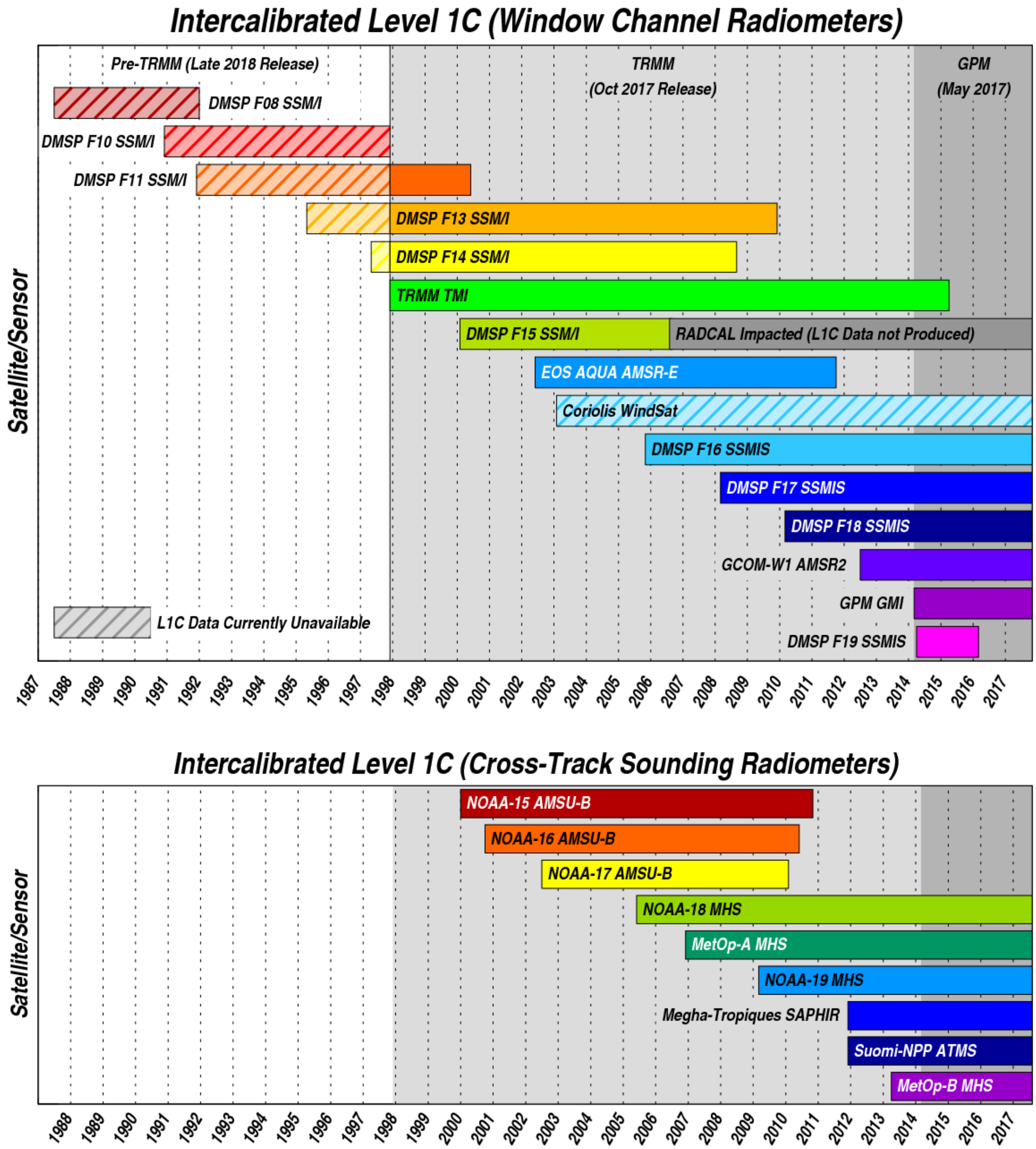

Figure N-3. Level 1C Data Availability for Version 8 TRMM Constellation

4. Based on the X-CAL team's recommendation, some data has been flagged as "bad" or "caution" in the Level 1C product due to poor data quality, sensor issues or failure. A detailed report on the Advanced Microwave Sounding Unit – B (AMSU-B) data quality from the X-CAL team follows the table below.

Sensor	**Channel**	**Start Date (Orbit)**	**End Date (Orbit)**	**Flag**	**L1C Tc**
SSMIS F16	150 H	20150501 (59504)	20150826 (61160)	Bad	Set to missing
	183+/-1 H	20131201 (52214)	20150826 (61160)	Bad	Set to missing
	183+/-3 H	20131201 (52214)	20150826 (61160)	Bad	Set to missing
	183+/-7 H	20131201 (52214)	20150826 (61160)	Bad	Set to missing
	91 V	20150424 (59413)	20150826 (61160)	Caution	
	91 H	20150424 (59413)	Ongoing	Caution	
SSMIS F17	37 V	20160405 (48595)	20160518 (49201)	Bad	Set to missing
	37V	20160803 (50286)	Ongoing	Bad	Set to missing
SSMIS F18	150 H	20120214 (11988)	Ongoing	Bad	Set to missing
AMSU-B NOAA-15	89	20090101 (55297)	End of mission	Bad	Set to missing
	183+/-1	20090101 (55297)	End of mission	Bad	Set to missing
	183+/-3	Begin	End of mission	Bad	Set to missing
	183+/-7	20090101 (55297)	End of mission	Bad	Set to missing
AMSU-B NOAA-16	183+/-1	20080101 (37503)	End of mission	Bad	Set to missing
	183+/-3	20080101 (37503)	End of mission	Bad	Set to missing
	183+/-7	20080101 (37503)	End of mission	Bad	Set to missing
AMSRE AQUA	89 A V+H	20041104 (13322)	End of mission	Bad	Set to missing

AMSU-B V05 Level 1C Release Notes (July 31, 2017)

The Advanced Microwave Sounding Unit-B (AMSU-B) is a cross-track scanning humidity profiler with channels near the 183 GHz water vapor line that flew on board the NOAA-15, -16, and -17 polar-orbiting spacecraft. Coincident observations were compared between the various AMSU-B sensors (Version TRMM005) and the Microwave Humidity Sounders (MHS) on NOAA-18 and MetOp-A. The MHS brightness temperatures (Tb) were recalibrated to GPM GMI (V05), which was adopted by the X-CAL team as the calibration standard for all the radiometers in the TRMM/GPM radiometer constellation.

Data Quality: The performance of the AMSU-B instruments on board both NOAA-15 and -16 was generally very poor, while the data from the NOAA-17 AMSU-B was quite good. Intercalibration offsets are applied to the Tb for the data range indicated by the green bars “good” in Figure 1, with the Tb corresponding to channels indicated by the red bars “bad” set to missing. Even within the “good” range, however, the data should be used with caution as there are variations in the calibration and biases across the scan that vary over time. The 183±3 GHz channel on NOAA-15 was especially problematic and has thus been set to missing over the entire data record. We do not consider this channel to be useful for any application. Both NOAA-15 and -16 also had severe degradation starting in 2008 for several of the NOAA-16 channels and in 2009 for several of the NOAA-15 channels (see Figure 2).

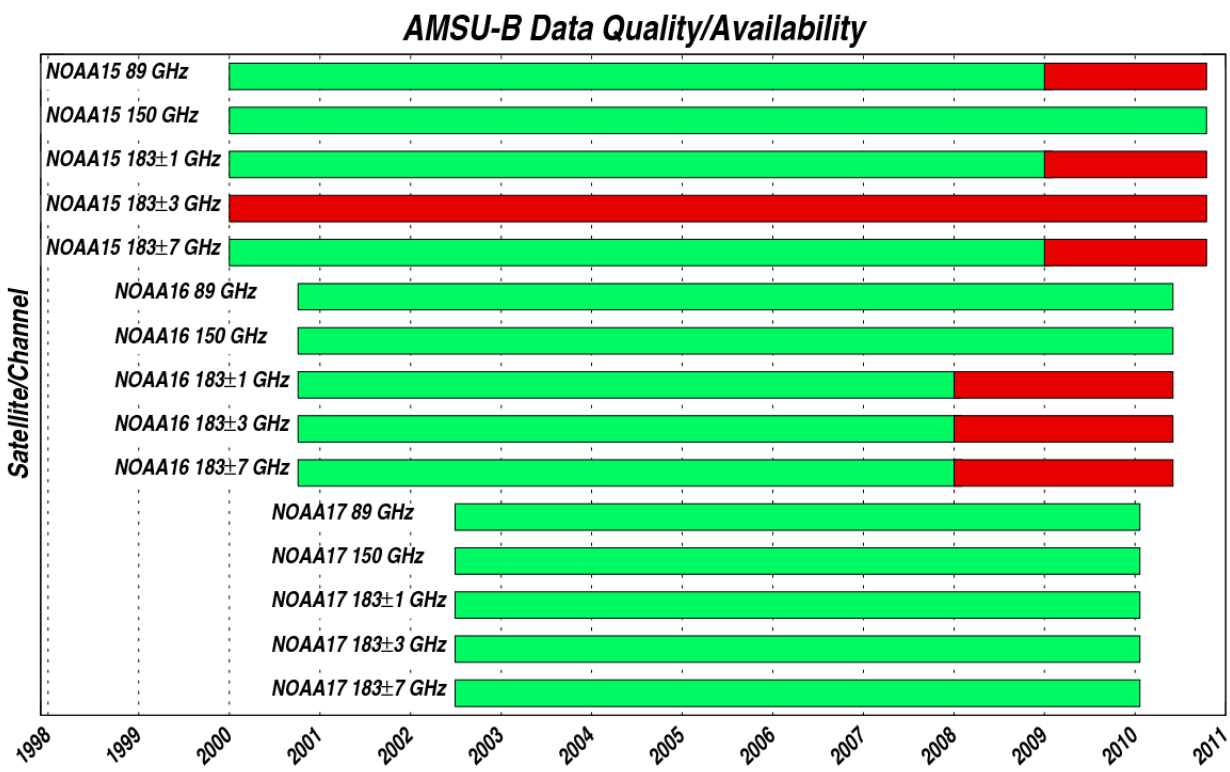

Figure 1: Data availability by channel for the AMSU-B instruments on board NOAA-15, -16 and -17. Green indicates data is useable, while red indicates that the data for a given channel has been flagged as bad and set to missing in the Level 1C data files.

NOAA-15 AMSU-B
89.0 GHz Useable through December 2008
150 GHz Useable over entire data record
183±1 GHz Useable through December 2008
183±3 GHz Not useable over entire data record
183±7 GHz Useable through December 2008

NOAA-16 AMSU-B
89.0 GHz Useable over entire data record
150 GHz Useable over entire data record
183±1 GHz Useable through December 2007
183±3 GHz Useable through December 2007
183±7 GHz Useable through December 2007

NOAA-17 AMSU-B
89.0 GHz Useable over entire data record
150 GHz Useable over entire data record
183±1 GHz Useable over entire data record
183±3 GHz Useable over entire data record
183±7 GHz Useable over entire data record

Time series of simulated minus observed Tb for the 183 GHz channels are shown in Figure 2 below for the AMSU-B instruments on board NOAA-15, -16 and -17 as well as the four MHS instruments on board NOAA-18 and -19 and MetOp-A and -B. This figure clearly shows the substantial degradation in the calibration in the NOAA-15 and -16 channels, as well as the variability in the 183±3 GHz channel for AMSU-B on board NOAA-15. Note that these are average differences, although the standard deviation in the single difference values also increases dramatically for NOAA-15 and -16 resulting in much larger instantaneous calibration errors that can have significant impacts on precipitation and other geophysical parameter retrievals.

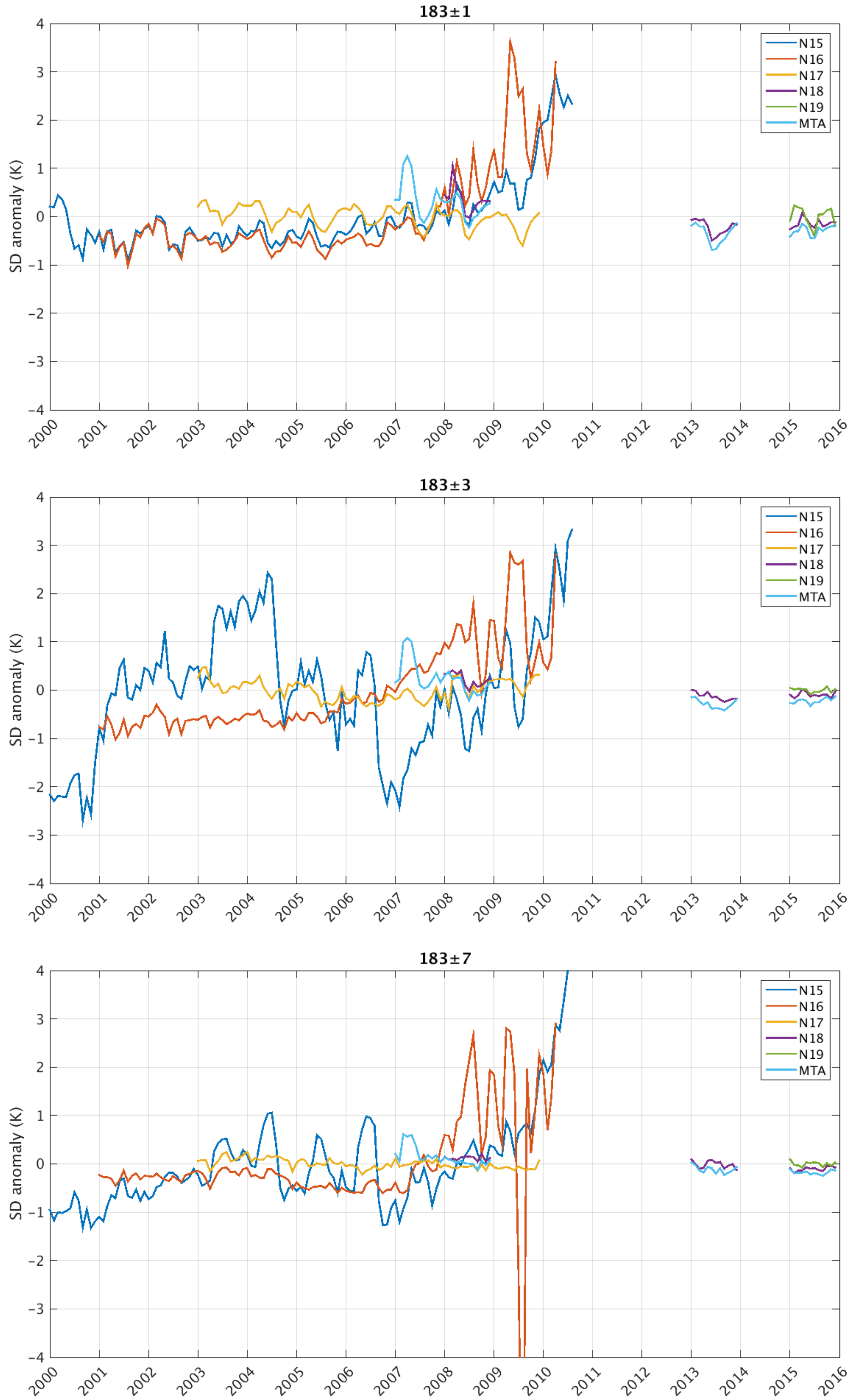

Figure 2: Time series of single differences (Observed – Simulated Tb) for the 183 GHz channels of the TRMM/GPM cross-track sounders. Theses plots and the associated analysis were produced by Rachael Kroodsma at NASA's Goddard Space Flight Center.

ACRONYMS USED IN THIS DOCUMENT AND ITS APPENDICES

AAPP	ATOVS and AVHRR Processing Package
AMSR2	Advanced Microwave Scanning Radiometer 2
AMSR-E	Advanced Microwave Scanning Radiometer – Earth Observing System
AMSU-A	Advanced Microwave Sounding Unit – A
AMSU-B	Advanced Microwave Sounding Unit – B
APC	Antenna Pattern Correction
ATBD	Algorithm Theoretical Basis Document
ATMS	Advanced Technology Microwave Sounder
ATOVS	Advanced TIROS Operational Vertical Sounder
AVHRR	Advanced Very High Resolution Radiometer
CLASS	NOAA's Comprehensive Large Array-Data Stewardship System
CLIM	Climatology
CSU	Colorado State University
DMSP	Defense Meteorological Satellite Program
DRD	Data Requirements Document
ECMWF	European Centre for Medium-Range Weather Forecasts
EIA	Earth Incidence Angle
FCDR	Fundamental Climate Data Record
FNMOC	Fleet Numerical Meteorology and Oceanography Center
FOV	Field of View
GCOM-W1	Global Change Observation Mission
GeoCP	GeoTK Control Parameters
GeoTK	(PPS) Geolocation Toolkit
GHz	Gigahertz
GMI	GPM Microwave Imager
GPM	Global Precipitation Measurement
GPROF	Goddard Profiling Algorithm
GSFC	Goddard Space Flight Center
GV	Ground Validation
H	Horizontal
HDF	Hierarchical Data Format
HDF-EOS	Hierarchical Data Format-Earth Observing System
HF	High Frequency
I/O	Input/Output
ICARE	Cloud-Aerosol-Water-Radiation Interactions
JAXA	Japan Aerospace Exploration Agency
JPSS	Joint Polar Satellite System
KAV	K, Ka, and V Bands
L1B	Level 1B
L1C	Level 1C
LAS	Lower Atmosphere Sounding
lat/lon	Latitude/Longitude
LF	Low Frequency
METOP	(European) Meteorological Operational (Spacecraft)
MHS	Microwave Humidity Sounder

MSPPS	Microwave Surface and Precipitation Products System
NASA	National Aeronautics and Space Administration
NetCDF	Network Common Data Form
NOAA	National Oceanic and Atmospheric Administration
NORAD	North American Aerospace Defense Command
NPP	Suomi National Polar-orbiting Partnership
OST	Orbit Start/Stop Times
PPS	Precipitation Processing System
PRT	Precision Resistance Thermometer
QC	Quality Control
QF	Quality Flag
QH	Quasi-Horizontal
QV	Quasi-Vertical
RADCAL	Radar Calibration
RFI	Radio Frequency Interference
SAPHIR	Sondeur Atmospherique du Profil d'Humidite Intertropicale par Radiometrie
SDR	Sensor Data Record
SGP4	Simplified General Perturbations Satellite Orbit Model 4
SSMI	Special Sensor Microwave Imager
SSMI/S	Special Sensor Microwave Imager/Sounder
STAR	NOAA Center for Satellite Applications and Research
Ta	Antenna Temperature
TAI	International Atomic Time
Tb	Brightness Temperature
Tc	Common Intercalibrated Brightness Temperature
TDR	Temperature Data Record
TIROS	Television Infrared Observation Satellites
TKIO	PPS Science Algorithm Input/Output Toolkit
TLE	Two-Line Element
TMI	TRMM Microwave Imager
TRMM	Tropical Rainfall Measuring Mission
UAS	Upper Atmosphere Sounding
UM	Users' Manual
V	Vertical (lower-case v stands for vector)
V03, 04	Version 03, Version 04
WG	W and G Bands
X-CAL	Intercalibration Working Group (GPM)
XML	Extensible Markup Language